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Heart-searching at Eastbourne

THE chill wind that has recently been blowing across the nuclear energy field was much in evidence at the F.B.I. Eastbourne Conference on Nuclear Energy. One of the avowed objects of the conference was to strip away the glamour and hoo-ha surrounding nuclear developments, but the gusto with which this task was tackled at times smacked of as much emotionalism as the fault that the conference set out to correct.

Certainly nuclear energy has been regarded in some quarters as something of a band-wagon which only had to be boarded to lead to effortless prosperity, and the international determination to discuss the subject in terms of a universal panacea for all economic and industrial problems has done little to dispel this view. Before, however, pouring too much cold water on nuclear developments and potentialities, it would be as well to consider the sources of excessive optimism and then the realities of the present situation.

Superficial discussions with some of the consortia might lead one to suppose that they had been led on, in ignorance of the real value of the new energy source, and only now were they in a position to obtain an accurate general picture of the opportunities. The Government White Paper published in February, 1955, called for the (then) daring project of installing 2,000 MW of uranium-fuelled electricity generating stations by 1965. It became clear as Calder Hall neared completion that this was a modest figure compared with what could be done. In March, 1957, the programme was revised and the installed capacity increased to 5/6,000 MW (E). Following this revision, many public statements were made calling for an even greater increase but neither the C.E.A. nor the A.E.A. implied that this would be approved. Admittedly a minor slowing down of the programme was announced last September but less than that applied to the bulk of large-scale construction.

Greatly increased size of station has, of course, been a complicating factor but there was no justification for assuming that numbers of stations would apply rather than installed capacity. Capital value—the governing factor—is nearly proportional to installed capacity irrespective of numbers. The change from 140 MW (E) per reactor to 400 MW (E) is unlikely to change capital cost per kW by more than 25%, a figure which also includes a significant percentage resulting from improvements in detailed design.

If therefore it is considered necessary to temper the enthusiasms of any specific bodies, perhaps the groups should become introspective and curb their own optimism rather than turn outwards to discourage others. In part, of course, the Eastbourne Conference did represent a self appraisal in a rather public manner and no doubt it was also primarily meant as a warning to any potential formers of consortia that the U.K. field was adequately filled and newcomers would not only be unwelcome but would find life highly unprofitable. Now this no doubt is true. The U.K. cannot support more than five consortia and there are those who feel that five is already too many, but we must be wary of generalizations which result in an attitude of pessimism more dangerous than the previous optimism.

The arguments concerning limited conventional energy resources put forward in 1955 are as valid today as then—moreover, three years' further supply of conventional fuel has been used up and we have had to suffer rationing through the Suez crisis. Nuclear energy has an assured expanding future, and public questioning of this, particularly in the presence of potential overseas customers, can do harm.

Equally serious is the harm that can be done to the component industry. Relations between the main groups and the component manufacturers have followed a pattern similar to that between the groups and the A.E.A. Initial disinterest, except on a cost-plus basis, resulted in a monopolistic attitude on the part of the groups which is now giving way to a healthier co-operation, in which component manufacturers are prepared to do their share of development work and take a reasonable gamble on the value of such development in subsequent markets. This relationship can suffer if doubts are now thrown upon the reality of the eventual markets.

A further danger of pessimism is inertia. These pages have emphasized the strength of the U.S. activities in Europe and, although Sir George Thomson suggested at the F.B.I. Conference dinner that U.S. companies regard exports as very much of a side-line, Sir Claude Gibb was swift to disabuse such an impression. Only by maintaining continuous pressure can we assure ourselves of even a modest slice of the European cake. By all means let us be realistic, by all means strip the hoo-ha, but don't let us swing as vigorously in the opposite direction and, incidentally, why strip the glamour?

Chemical Industry Participation

IT is understood that the chemical industry is to be invited to take a more direct part in atomic energy developments than hitherto. It seems that the A.E.A. is now hoping that it can farm out to industry, on a sub-contract/educational system similar to Calder Hall, some of the responsibilities that, so far, have been exclusively Government held. No statement has been made on the detailed mechanism of procedure to be adopted, nor exactly the processes which will be affected. It would appear that there are four main classes of work which could be placed on a commercial basis—isotope separation, ore treatment, fuel element fabrication and spent fuel element processing.

Isotope separation is not confined to the uranium plant at Capenhurst which for some years to come will be a military installation and as such will be owned and probably operated by the Authority for the Government. It would not be impossible, of course, for the operation of this plant to be handed to an industrial concern—the practice is common in America of companies operating whole plant for the A.E.C.—but, in this country, it is unlikely that the U.S. system will be adopted. Even when significant supplies of enriched fuel for reactors become available, Capenhurst will almost certainly remain a wholly owned and operated A.E.A. plant. Where the material being handled is not fissile, and when the end product is not of a military character, B^{10} production has already set a precedent of commercial exploitation. The first column was erected by 20th Century Electronics in the middle of 1956 and this has been further augmented since. The other stable isotope for which commercial demands are likely to be considerable is, of course, deuterium. In view of the advanced state of the feasibility studies of new separation processes and the rising promise of the heavy water gas-cooled reactor, there is reason to suppose that commercial development of this process would come fairly high on the industrialization list.

Production of uranium slimes and concentrates is substantially a commercial procedure at the present time. As far as this country is concerned uranium is imported in the concentrate form and in many instances mining and concentration has been carried out entirely by industrial organizations. There is no real reason why commercial interests in this country should not take over from this point and continue the process to the pure metal. Whether there are any advantages to be gained in a commercial organization taking over the Springfields factory is doubtful but the demand for uranium will increase progressively probably over the next two decades and new plants will have to be built. Detailed figures of the U.K. imports of uranium have not been published and it is difficult, therefore, to obtain a real assessment of the total capacity of the Springfields works, but there is little doubt that the commercial power programme will require new plant facilities which, in addition, will incorporate improvements in design that have been made over the past years. It is anticipated that a free world market in uranium will be eventually set up and in this country it would seem logical, therefore, that the process be handled by industry in the same way as other raw materials.

Fuel element fabrication is not quite so straightforward. Elements for the first power stations are certainly amenable to normal commercial treatment as numbers are large, allowing mass production methods to be used and the material is natural uranium. However, should future policies of fuel cycling demand initial enrichment or plutonium spiking, then it may well be felt that this is not a process for an ordinary commercial undertaking. Nevertheless, the chemical industry is currently handling problems equally as great as those encountered in the handling of slightly enriched material and providing the range of designs does not call for a wide range of element material (which in any case presumably the C.E.G.B. would deprecate), fuel element fabrication could readily become a commercial procedure. Already in the United States, a number of companies have set up highly successful plant for the production of fuel elements with significant U^{235} enrichment.

Problems are much more acute when it comes to spent fuel element treatment, in which highly active material is to be handled and pure fissile material—plutonium—is to be extracted, with the consequent safety problems concerning criticality (the general problems to be encountered in fuel element processing are discussed in an article in this issue, p. 191). It is probable that for some years to come the overriding consideration will be the safety aspect and it is unlikely that the Authority will feel prepared to allow fuel element reprocessing out of its direct jurisdiction. In addition, no doubt, it would be difficult to find companies who, without a prolonged period of design experience, would be prepared to invest very large sums of money in a plant which, because of radioactivity cannot be inspected and maintained.

On the whole then, it would seem that the immediate projects ready for commercial exploitation are heavy water separation, natural uranium processing and fuel element fabrication for the base load stations. Nevertheless, there is still a great deal of design work and construction work to do on the element treatment side and also on the enriched fuel side. Whereas one would expect the traditional chemical industry to be the main participants, there would also seem to be an opportunity for the consortia's design teams to assist in the design of new plant. The type of techniques and flow sheets met with in a power station are not dissimilar from those encountered in a chemical plant and, at a time when the consortia are concerned with the difficulties of maintaining a steady load on their design departments, the second avenue that the chemical engineering field offers would seem to warrant the closest investigation. There is no reason, of course, why their activities should be confined to the nuclear energy field, but their special experience in designing plant for handling radioactive material makes them peculiarly qualified to do this class of work.

Commentary

Financial Aspects of Nuclear Energy

Amongst the many excellent papers read at the F.B.I. Conference on Nuclear Energy at Eastbourne, probably the most outstanding was that prepared by J. R. Cuthbertson and J. Broderick on Financial and Investment Aspects of Nuclear Energy including Home and Overseas Markets. In its printed form this made a formidable document of over 60 pages and it is impossible to try to compress this into a short synopsis. There is little doubt that the paper will be a source of reference to nuclear engineers for a long time to come. In Part I, The Background to Nuclear Energy Finance, the scale of nuclear energy investment is placed in perspective alongside such vast capital undertakings as the Aswan Dam and the Snowy River project. A very careful analysis is also made of the effect of interest rates and load factor, and interesting comparisons are made with conventional stations and the change in pence/kWh with ton/miles for fossil fuel transport. Part II of the paper entitled "The Problems of Financing Nuclear Energy" discusses at some length this aspect of nuclear developments, both from the point of view of the U.K. and financing overseas installations.

It was, perhaps, unfortunate that in their verbal introduction to the paper the authors should spend so much time on economic theory, which seemed oddly unrelated to the realities of nuclear energy developments. In particular, the philosophy that because of the probable improvements in power station design we should be wary of building nuclear power stations now rang wholly false. The Chairman of the session, Mr. West, was not able to contain himself on this point in his summing up and pointed out that progress in design is very largely dependent upon constructional experience and delaying the programme today inevitably meant decreasing the rate of progress. Whilst their criticisms of the artificial prices for plutonium may be justified, their scepticism on the realism of the price of uranium seemed unnecessary and Mr. Peirson, the Secretary of the U.K.A.E.A., whilst exhibiting the common reluctance of members of the Authority to speak "off the cuff" on such matters, pointed out that calculations on uranium costs were made in exactly the same way as calculations on the costs of other manufactured goods. Nevertheless, in spite of the somewhat unsatisfactory nature of the summary and the discussion which followed, the paper represents a very real contribution to the literature on nuclear energy and provides the working engineer with a real insight into the financial aspects of his developments.

B. and W. and A.P.C.

Babcock and Wilcox and Atomic Power Constructions, Ltd., have concluded an agreement whereby Babcock and Wilcox will undertake the design, manufacture and erection of reactor pressure vessels. At first sight this might seem contrary to the original conception of the consortia wherein the various companies were enclosed in watertight compartments with virtually no interchange. On the other hand, Atomic Power Constructions, Ltd., did not contain a company in a position to handle the very heaviest engineering problems met with in reactor construction, and Babcock and Wilcox was the logical company to turn to in the circumstances. In addition, the tie-up between English Electric, Taylor Woodrow and Babcock and Wilcox is not quite as tight as is found, say, in the Nuclear Power Plant Company, and there has always been a greater tendency for the component companies of the Hinkley Point consortia to be individually identified than with other consortia. Whether in later years this new arrangement will mark the beginning of the break-up of the rigorously tied companies probably depends more on the C.E.G.B. than on the individual companies. The present C.E.G.B. attitude towards block contracts appears to be that this system will be adopted provided that the present intense competition continues and a reasonable proportion of the work is sub-contracted to outside companies. Ultimately, it is likely that the C.E.G.B. will revert to their traditional method of ordering, but this will almost certainly not be for some years yet.

A.E.I. Reorganization

One group that has always given rise to speculation on the stability of the consortia is A.E.I. which comprises, amongst others, BTH and Metropolitan-Vickers. There have been many who felt that the compounding of these two companies into one consortium was illogical and that greater opportunities would be afforded A.E.I. if the interests of the two companies were split amongst two consortia. At the same time, their position in the conventional electricity supply industry has always seemed slightly anomalous—these two large companies competing and yet forming part of the same group. At the 58th Annual General Meeting of A.E.I. Ltd., however, the Chairman, Lord Chandos, gave notification of the reorganization that was to take place in the group to eliminate duplication of effort and make the best use of all personnel currently employed by BTH and M.-V. and of all the manufacturing facilities available. In his report Lord Chandos stated that they had decided that over the next few years they would change to a divisional organization based on products. The three principal operating companies, BTH, M.-V., and S.E.S., will manage various A.E.I. divisions under a policy laid down by the board of the A.E.I. These companies will remain the instruments through which general A.E.I. policy is carried out and they will devolve some of the day-to-day executive work upon the divisions. Initially two A.E.I. divisions are being formed. The A.E.I. turbine generator division will be managed by M.-V. and the A.E.I. heavy plant division by BTH. These divisions will control the design, manufacture and sales of all products falling within these categories. This statement then finally quashes the notion that either Metropolitan-Vickers or BTH would leave the A.E.I.-John Thompson consortium and become a member of another consortium or operate as a free-lance company; (present agreements with John Thompson cover a five-year period). The new reorganization seems, of course, sound and logical, but there will be many, perhaps

more sentimentally inclined, who will regret the passing of the M.-V. BTH competition era and the ultimate disappearance of these names from the fascia panels of equipment.

Euratom and the U.S.A.

The ties between the U.S.A. and Euratom were considerably strengthened by the meeting held in Luxembourg at the beginning of April. These discussions are to be continued in Washington, but it is understood that, at the Luxembourg meeting, agreement was reached on a joint two-year research programme. This is believed to involve an expenditure of around $200 million which would be paid for equally by Euratom and America. An official communiqué indicates that agreement has been reached on guarantees for enriched fuel but details of this agreement were not included. It will be interesting to see whether any modification is made to the plans for the Eurochemic processing plant at Mol to cater for enriched fuel rather than natural uranium. It is likely that U.S. pressure will be brought to bear on this project, although it must be remembered that this is an O.E.E.C. undertaking and not just a Euratom plant. With Britain co-operating only from the sidelines, however, the most influential countries in the project are the Euratom group. The original five-year plan for U.S. reactor building in the Euratom countries represented only one-fifteenth of the wise-men ten-year recommendations, but it is doubtful whether the figure of 15,000 MW by 1967 will be achieved, and it appears now most unlikely that the U.S. contribution will remain at the original low figure.

Electricity Council Statistics

Figures have now been published of the units sold by the Central Electricity Generating Board for the period ended February 28, 1957. These show an increase over the previous 12 months of 7.4% as compared with 5.1% for the preceding 12 months. There have been indications in the United Kingdom that the forecast increase in power requirements usually expressed as a doubling every 10 years, would not be realized and that a significant levelling off in demand would be experienced. These latest figures indicate that whilst a slowing-down trend was becoming evident over the middle period of 1957, 1958 has seen a progressive increase. Adjustment to normal weather and standing working days, modifies the figures to a certain extent—the twelvemonth increase decreasing from 7.4% to 7.2% and the preceding minimum twelvemonth figure (up to August 31, 1957) increasing from 3.7% to 6.2%, but the general upward trend in the consumption curve is not altered. Certainly the figures as published indicate that the doubling period will not be greatly in excess of 10 years and should not lead to any signficant modification to the projected energy programme over at least the next decade.

Technical Progress Review

The U.S.A.E.C. has recently published the first in a series of technical progress reviews which are summaries, designed to provide American industry and science with authoritative reports on important technological work as it emerges from nuclear research and development programmes. The summaries are not meant to be comprehensive abstracts of all published material in the field of civilian reactors but they nevertheless provide a valuable cross-section of recent work. The first of these summaries prepared by Dr. Zinn and associates dealt with power reactor technology and this has now been followed by a summary on reactor core materials prepared by the Batelle Memorial Institute. The reviews will, no doubt, be read with interest in countries outside the United States and should provide a valuable running commentary on technological developments.

Homogeneous Experiment

A new zero energy reactor has gone into operation at A.E.R.E. Harwell to obtain basic nuclear information on homogeneous systems. The original apparatus ZETR, built at Harwell, was transferred last year to Dounreay for criticality experiments and the new reactor has been christened HAZEL rather than ZETR II for obvious reasons of pronounciation. HAZEL uses enriched uranium fuel in the form of uranyl fluoride dissolved in heavy water. It is contained in a stainless-steel cylinder 7 ft by 2 ft diameter surrounded by a graphite reflector; the fuel solution is pumped into the cylinder from two storage vessels located nearby. Criticality is controlled by adjusting the level of the solution in the reactor vessel and by moving a vertical cadmium control plate into the gap between the steel cylinder and the reflector. Two cadmium plates similar to the control device are used as shut-off rods and two additional shut-off rods can be dropped vertically into the fuel solution in the vessel. The reactor will be operated at a power of less than a watt and cooling is not necessary.

The homogeneous reactor, particularly when moderated with heavy water offers considerable promise from the physics point of view for a simple power reactor. Unfortunately the corrosion problems are formidable and development has not proceeded at a rate that at one time was envisaged. Discussions are still in train with the O.E.E.C. for the construction of a full-scale experiment at the Winfrith Heath site. It is probable that this project will go ahead, but no final decisions have yet been reached and the anticipated time scale has not been disclosed.

ZETA Team Award

If the delay in announcing the results that were obtained last August with ZETA—the Zero Energy Thermonuclear Assembly—still rankled with the team that built it (and we suspect that this topic has received rather greater publicity than it warranted) the presentation of the Hulton Achievement Award will have provided both honorary and practical evidence of appreciation of their work. The ZETA team was unanimously chosen by the panel of distinguished judges to be the first recipients of this yearly award, which has been given by Sir Edward Hulton and comprises a silver trophy and medal and £1,000 in cash. Sir John Cockcroft accepted the award on behalf of the team and emphasized that he did not wish for any more personal publicity on this subject and was glad that the men who had done the work were being recognized and it was they who would divide the cash award amongst themselves. No doubt the 16 members of the team concerned will find good use for the money and no doubt their wives will feel that this is some compensation for the many hours of overtime that their husbands have put in.

There will be little easing up, however, in the ZETA programme as work is proceeding with modifying ZETA I to achieve higher temperatures (15M°C) and it is understood that a second model is now to receive high development priority. It is believed that the goal of this second model is 100M°C and although the toroid will be basically the same as ZETA I no doubt different constructional materials will be necessary and stainless steel would seem to be the logical answer—although more exotic materials may be required before the break-even point is reached. An equipment cost of £300,000 has been quoted for ZETA I but obviously further models will be much more expensive and will require the formation of a larger development team.

Chemical Processing for Nuclear Energy

—Its Problems and Importance

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Improvements in fuel element economy lead to more chemically intractable fuel in even more intractable canning. This article discusses some of the problems arising.

THE principal contributions to the cost of nuclear power arise from capital charges, fuel costs and operating costs. Future decreases in the overall cost of power from gas-cooled, graphite-moderated reactors (Fig. 1) have been predicted by Sir Christopher Hinton,[1] based on reductions in capital and fuel costs following straightforward engineering advances and better fuel utilization. The fuel cost contribution depends on the initial charge for the fuel and the irradiation level which can be reached before it must be removed from the reactor for chemical processing.

There are three main reasons why chemical processing of irradiated fuel should be necessary, any of which may demand the removal of the fuel before its original fissile content is adequately used up. These are:—

1. To recover fissile Pu^{239} or U^{233} that is artificially produced from the naturally occurring " fertile " U^{238} or Th^{232}. This fissile material can then be used to fuel some new reactor or recycled within the parent reactor. An outline of possible thorium and uranium fuel cycles is shown in Fig. 2.
2. To restore the reactivity of the fuel which decreases during irradiation (in the manner shown, for natural uranium fuel, in Fig. 3) owing to burn-up of fissile material and wasteful absorption of neutrons in fission products.
3. To restore the physical and structural properties of the fuel. Irradiation causes damage which might ultimately lead to failure of the fuel elements.

Cheaper power will, therefore, result from the use of fuels which can withstand longer irradiation before reprocessing is necessary (Fig. 4). This object may be achieved by the use of a higher fissile element concentration to provide excess reactivity in the initial fuel; by improving the neutron economy of the reactor; and by employing the fissile material in a form less susceptible to radiation damage. It is likely that non-metallic compounds, special alloys, or, in certain cases, fluid fuels will be needed to withstand the irradiation levels considered necessary for economic power production.

The irradiated fuel will have a credit value by virtue of the residual fissile material that it contains. This value is set by the current market value of the fissile material, modified by the cost of the chemical processing needed to recover it and convert it to a usable form. With longer irradiation times (i.e., greater burn-up) a point can be envisaged where the value of the residual fissile material may be less than its cost of recovery, so that spent fuel could be rejected (although the costs of safe storage or disposal would still have to be met). This situation is unlikely to be reached in the near future with enriched fuels, and, even with natural uranium, it may be necessary in the long term to consider the recovery of fertile (U^{238}) as well as fissile material. Chemical processing is thus likely to contribute a permanent fraction of nuclear fuel costs.

Types of Fuel Element

A fairly wide variety of reactors might be employed for the generation of nuclear energy, combining variations of fuel, moderator and heat transfer fluid, and the principal types currently under development are shown in Table 1. The fuel for use in these reactors must have the necessary properties for:—

1. Long irradiation stability.
2. Resistance to the corrosive action of the appropriate heat transfer fluid and/or moderator.

The first requirement may lead to fuel in the form of metal alloys, ceramic-type compounds, dispersions in metal or ceramic materials, or aqueous, liquid metal or fused salt solutions or slurries of uranium, plutonium, thorium and their compounds. Protective cans of aluminium, magnesium alloy, beryllium, stainless steel, zirconium, niobium, etc.,

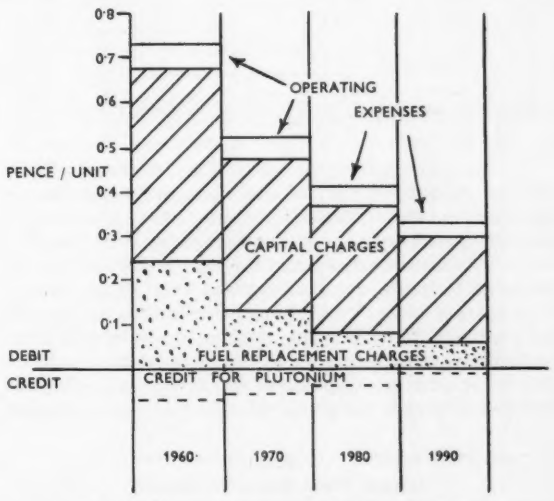

Fig. 1.—Forecast of decrease in costs of nuclear energy (after Hinton).

may be required to provide the appropriate corrosion resistance. It is desirable, in addition, that the fuel itself should be resistant to the corrosive conditions and, in some reactors, the use of the fuel in a particular chemical form is dictated by this requirement; for example, the use of uranium dioxide in reactors cooled by high-pressure water.

A wide variety of fuel elements will thus arise from a power programme which is based on a diversity of reactor types. Processing facilities must be capable of dealing with these fuels at a cost and efficiency consistent with the economic generation of power. (Homogeneous reactors

employing continuous fuel reprocessing, in which the chemical plant is an integral part of the reactor system, are not discussed.)

Economics of Fuel Reprocessing

The demand for power costs competitive with those for conventional sources dictates a certain maximum allowable charge for reprocessing. Any estimate of the magnitude of this charge rests upon a number of assumptions about the overall cost of power and the contributions made by capital costs and fuel burn-up. To meet a total power cost of 8 mill/kWh for the U.S. economy, Bruce[2] has estimated that the cost of reprocessing should not exceed 0.4 mill/kWh assuming 4,000 MWD/te irradiation.

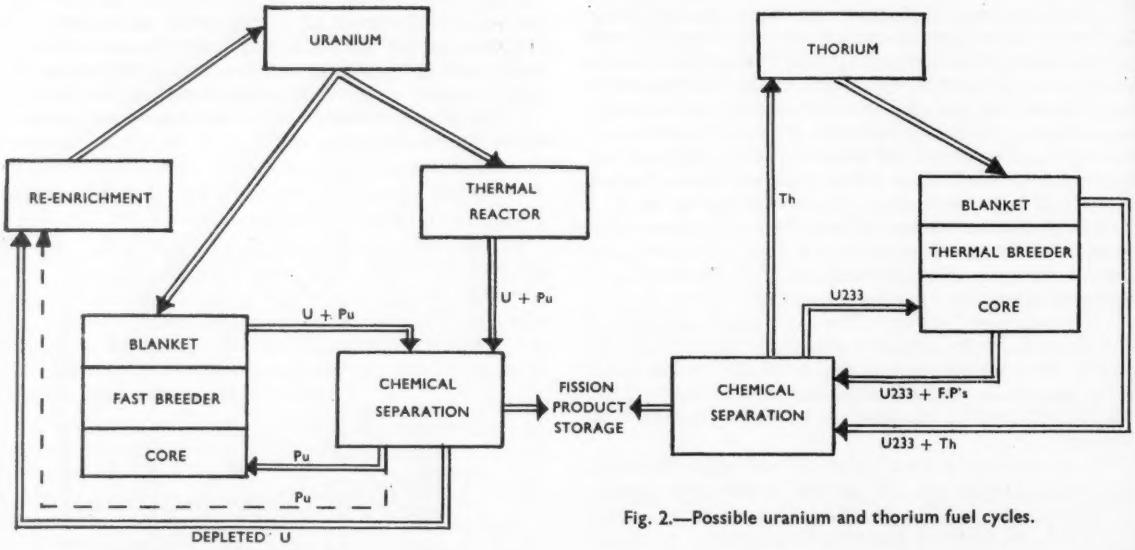

Fig. 2.—Possible uranium and thorium fuel cycles.

The nuclear fuel reprocessing plant requires a large number of supporting facilities such as health physics organization; close analytical control and fissile material accounting; effluent disposal and storage facilities. Together with criticality restrictions and shielding requirements, this means that reprocessing costs have to bear a high level of fixed charges and are, therefore, very sensitive to throughput (see Fig. 5). For the attainment of an allowable reprocessing cost, per unit of electricity, sufficient irradiated fuel must arise to keep an economically sized plant in operation. On the foregoing assumptions, Bruce estimates a necessary throughput of at least 4 tons uranium/day. In general, this leads to two main conclusions:—

1. Chemical reprocessing of irradiated fuel cannot be an economic proposition unless it serves a nuclear generating system of sufficient size.
2. The chemical process must be sufficiently versatile to accept and convert to a common feed the diverse types of irradiated fuel arising from a number of reactors. Conversely—for economic reprocessing—a degree of standardization of fuel elements is desirable.

TABLE 1
Principal Power Reactor Possibilities

Category	Fuel	Coolant	Moderator
Thermal	Natural or near-natural uranium.	Gas	Graphite
	Natural or near-natural uranium.	Heavy water or gas	Heavy water
	Slightly enriched uranium.	Light water	Light water
	Slightly enriched uranium.	Light water	Graphite
Intermediate	Slightly enriched uranium.	Sodium	Graphite
Fast breeder	Highly enriched uranium or plutonium with natural uranium or thorium blanket.	Sodium	None
Homogeneous reactor	Solution of enriched uranium salt in heavy water with thorium blanket.	Heavy water	Heavy water
	Liquid metal alloy of plutonium or uranium with thorium blanket.	Liquid metal	None or graphite

Type of Process

The basic chemical problem in reprocessing is to separate fissile, fertile and fission product materials. The presence of a protective cladding or inert diluent material complicates the problem, particularly insofar as it may be necessary to remove this before the fuel can be treated.

Because of the high value of the fissile material, an extremely high recovery efficiency is demanded of the chemical process. The gain of fissile material in a breeding reactor could be quickly lost by a chemical process operating at, say, only 95% efficiency. A further requirement relates to the degree of removal of fission products for subsequent handling of the fuel for refabrication.

Manual refabrication requires almost complete decontamination, not only from fission products, but also from those highly-active isotopes of the fissile or fertile elements (e.g., U^{237} and Th^{234}) which are formed by nuclear side reactions. These isotopes are not separable by chemical means and, in most fuel cycles, the irradiated fuel is allowed a "cooling" period during which these isotopes decay to reasonable levels, before chemical processing. The cooling period also allows for the decay of the short-lived fission products and of the fissile element precursors Np^{239} and Pa^{233}.

At the present time possible chemical reprocessing techniques fall into three main categories:

1. Solvent extraction from aqueous solutions.
2. Volatility processes.
3. Pyrometallurgical processes.

Each relies on the existence of mechanically separable phases between which the fission products and the fissile and fertile elements are differently distributed.

Design Features of Separation Processes

Two major factors distinguish the processing of nuclear fuels from other types of industrial chemical process and fundamentally influence the design of the chemical plant. These are: 1. The highly penetrating radiation associated with the fission products. 2. The phenomenon of criticality.

The former implies that remote handling behind heavy shielding is required, and that plant maintenance, as normally understood, is not practicable, at least, in the primary stages. The plant must, therefore, be designed so that all essential operations with the highly active material, including analytical sampling, can be carried out by remote control and that only the minimum of maintenance is required. Any unavoidable maintenance must be capable of remote execution or, alternatively, provision must be made for decontamination to allow direct maintenance. Exceptionally high standards of plant construction are essential and, in particular, welds in vessels and pipelines must be guaranteed perfect. X-ray inspection of all welds is required in the regions of highest activity. Conventional

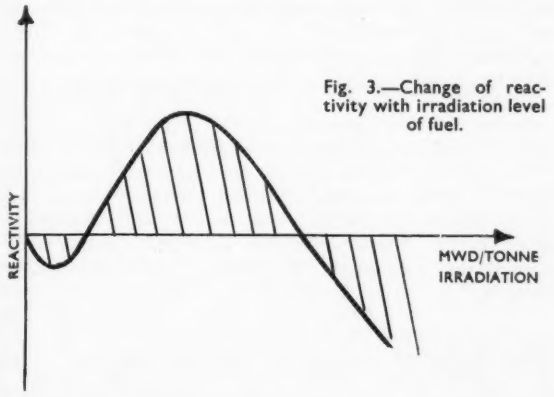

Fig. 3.—Change of reactivity with irradiation level of fuel.

items of equipment, such as pumps and valves, which normally require regular maintenance, must be eliminated or redesigned to new standards. Alternative methods of liquor transfer such as vacuum transfers, air lifts and gravity flow are widely used.

Criticality, i.e. the condition where a diverging fission chain becomes possible, requires that all processes handling fissile materials must be designed to avoid unwanted critical conditions. Control may be achieved by limitations of mass, concentration or geometry, which in many cases demands a complete revision of design parameters for plant units. A factor in achieving economical chemical processing is the degree to which design engineers are ready to combine conventional practice with more novel principles necessitated by the peculiar problems of radioactive processing.

The restrictions of criticality dictate much more lavish spacing of plant units than is usual in chemical plants. The shielding called for by high levels of activity also takes up a great deal of space. These facts alone contribute significantly to the high capital cost of these plants.

Solvent Extraction

Solvent extraction processes are well established in the nuclear field, and reprocessing plants built now to handle large quantities of irradiated fuel would almost certainly be of this type.

In this type of process the separable phases are an aqueous solution of the irradiated fuel and an organic solvent. Nitric acid solutions are usually employed because of the existence of suitable solvent-extractable nitrate complexes of plutonium, uranium and thorium together with the high solubility of plutonium, uranium, thorium and the fission product elements in this acid and

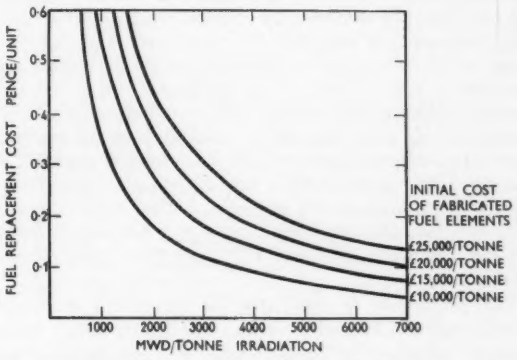

Fig. 4.—Effect of initial fuel cost and irradiation level on the cost of fuel replacements.

its compatibility with stainless steel plant. Typical organic solvents are tributyl phosphate, dibutyl carbitol and methylisobutylketone.

Under oxidizing conditions and at the correct acidity, uranium and plutonium can be extracted into the solvent phase, whereas the bulk of the fission products are not extractable. Subsequently, reducing conditions can convert plutonium to the only slightly extractable trivalent state; a further phase-separation process separates uranium and plutonium. Changes of acidity and solvent concentration suffice to separate thorium from uranium. Further solvent cycles purify the separated uranium, plutonium or thorium streams. This type of process operates at an extremely high efficiency and yields the very high fission product decontamination factors (ca 10^8) required for manual refabrication of the fuel.

An initial cooling period is desirable because it also allows the decay of radioactive iodine which might otherwise be released during fuel dissolving, or extraction into the solvent, and contaminate later parts of the process. It also reduces the extent of solvent radiolysis, but this is not now considered to be a seriously limiting factor.

In this country two large-scale fuel reprocessing plants exist at present based on solvent extraction. At Windscale the plant is concerned with processing natural or only slightly enriched fuel. At Dounreay the plant is tied to

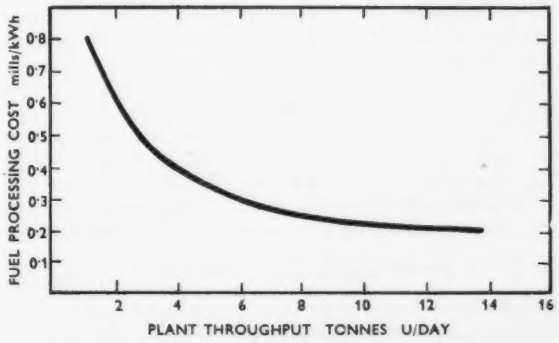

Fig. 5.—Effect of plant throughput on fuel processing cost (after Bruce).

the fast reactor experiment and has been designed specifically for enriched uranium and possibly, ultimately, plutonium fuels.

An outline of the Windscale process is given in Fig. 6. After the initial cooling period (under water shielding), the outer cans (aluminium or magnox) of the fuel elements are mechanically removed by remote control. The fuel is then continuously dissolved in nitric acid and fed to a series of solvent aqueous contactors where the separations are carried out. In this plant the contactors are vertical packed columns, which have the advantage of no mechanical moving parts and hence need little or no maintenance. The columns are arranged in a vertical sequence so that the active solution flows through the plant by gravity. Following separation, the uranium, in the form of uranyl nitrate, is returned to Springfields factory for re-enrichment to the required level in U^{235}, prior to fuel-element refabrication.

The plutonium is converted to metal via an oxide-fluoride-calcium reduction route. The highly-active fission product solution is concentrated by evaporation and stored in heavily shielded tanks. The low-activity wastes from the purification cycles are treated to bring them to an acceptable standard for discharge to sea.

The concentration of fissile material in the solution in this plant is sufficiently low to ensure that criticality does not become a limiting design factor until the plutonium purification process is reached. Plutonium criticality is controlled chiefly by plant geometry to the point where solid chemistry is introduced. In the final stages sub-critical amounts are handled batch-wise, but it should be pointed out that criticality is not the determining factor for this mode of operation.

The object of the Dounreay fast reactor fuel reprocessing line, outlined in Fig. 7, is to separate enriched uranium from fission products and parasitically-produced plutonium (the uranium is not 100% U^{235}). The natural uranium used for plutonium breeding is to be chemically processed at Windscale.

With the benefit of several years experience of the operation of the Windscale plant and the advances made by research and development during these years, many improvements were incorporated in the design. Because of the degree of enrichment, criticality restrictions affect the design of the entire plant. Control by geometry is employed, the process being continuous. Instead of vertical columns, horizontal mixer-settler contactors are used, which makes construction and shielding cheaper. Air-pulsing provides the mixing impetus so that no moving parts are in contact with the active solutions. The mixer-settlers themselves are of special design incorporating an in-line arrangement of mixers and settlers so as to achieve the desired throughput rates within an " eversafe " geometry. Liquor is enabled to flow through the plant by gravity by virtue of a small difference in height between each bank of horizontal mixer-settler units. The plant includes a line for refabricating fuel elements from the recovered fissile material under α-active conditions.

It should be pointed out that there is no difference in principle, between solvent extraction plants for processing natural uranium and those for enriched uranium and there is no technical reason why all enrichments could not be processed in the same plant. But it is obviously undesirable to mix different enrichments and the criticality restrictions necessary for highly enriched uranium would unduly restrict the throughput for natural and near-natural uranium.

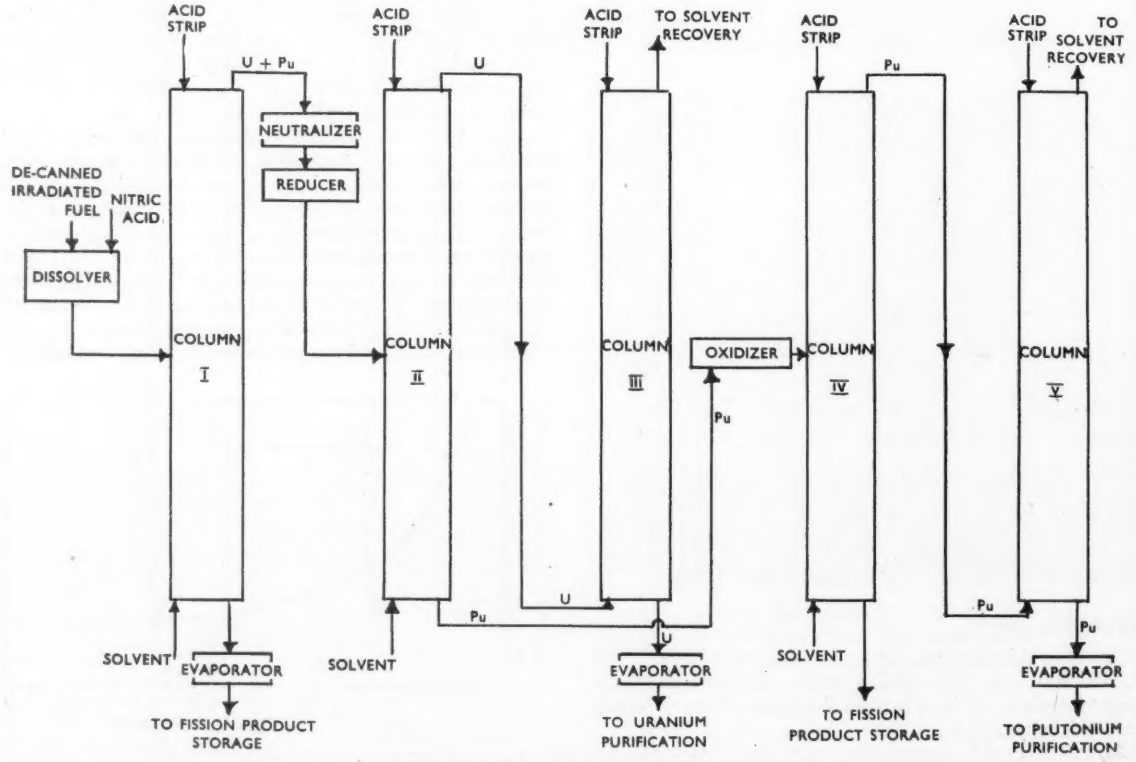

Fig. 6.—Outline of the Windscale separation process.

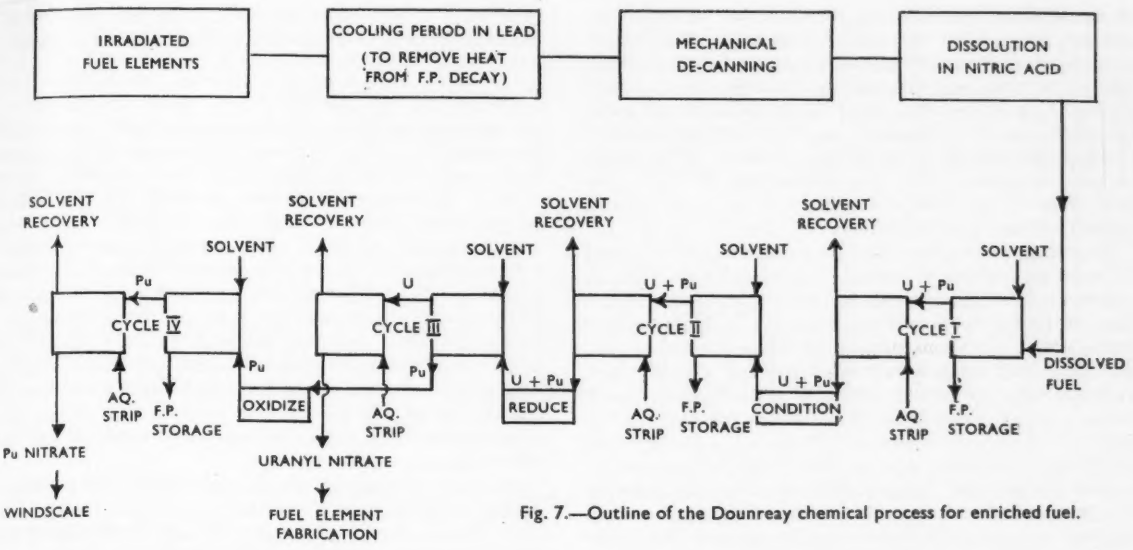

Fig. 7.—Outline of the Dounreay chemical process for enriched fuel.

Processing Advanced Elements by Solvent Extraction

The more stringent the operating conditions of the fuel element, the more difficult it becomes to process. The conversion of the fuel to a solution in nitric acid becomes in many cases the major chemical problem, since resistant canning materials are equally resistant to conventional dissolution techniques and the more complex fuel element shapes demanded by higher fuel ratings are correspondingly more difficult to de-can mechanically. The choice between mechanical or chemical methods for can removal must rest upon a comparison of the economics of complex remote mechanical operations (which may be rather specific to fuel shape) and solid waste disposal, versus more versatile chemical attack in specially resistant plant and disposal of fission product wastes in solutions containing a high proportion of "inert" fuel element structural material (and hence capable of only limited concentration).

The chemical preparation for solvent extraction of fuels (metallic and non-metallic) canned in, dispersed in or alloyed with such materials as stainless steel, zirconium, beryllium, niobium, molybdenum, silicon, graphite, beryllia, magnesia, etc., is under active investigation. Some possible methods of chemical attack and the subsequent conditioning for solvent extraction from a nitrate system are shown in Table 2.

These "head-end" treatments will involve the use of dissolvers, etc., constructed from resistant materials such as titanium, or tantalum. The removal of solid residues or sludges is, in many cases, an essential step and the development of filtration or centrifuging units, capable of simple and reliable operation in regions of high activity, is required. These measures, together with increased highly active storage costs, may add appreciably to the cost of processing advanced fuel elements by solvent extraction, and this fact must be considered when comparing solvent extraction with alternative reprocessing techniques.

TABLE 2

Possible Head-end Treatments for Solvent Extraction Re-processing of some Advanced Fuel Types

Fuel type	Possible Head-end Treatment for Aqueous/solvent Extraction Processing
Stainless steel (can or matrix)	Total dissolution in dilute aqua regia. Distil off chloride to give solution in HNO_3. Adjust acidity for solvent extraction.
	Anodic dissolution in HNO_3. Remove solid residue.
	Dissolution of stainless steel in H_2SO_4. Remove solid residue and dissolve uranium in HNO_3 or dissolve completely in H_2SO_4 followed by HNO_3.
	Carburization of stainless steel in methane at ~1,000°C. Dissolve in HNO_3/urea. Remove solid residue.
Zirconium (can or alloy)	Hydrochlorinate and remove zirconium as volatile $ZrCl_4$. Dissolve UCl_3 in water, add HNO_3 and distil off chloride. Adjust acidity.
	Total dissolution in HNO_3—$Al(NO_3)_3$—HF mixture.
	Dissolution of zirconium in aqueous HF. Remove solid residue. Dissolve uranium in HNO_3/Al $(NO_3)_3$.
Uranium-Molybdenum alloys	Dissolution in nitric acid. Remove solid molybdic acid.
Uranium carbide fuels	Dissolution in nitric acid. Remove carbon residue.
Dispersions in graphite	Leach with HNO_3 or HNO_3/HF. Remove solid residue complex fluoride with $Al(NO_3)_3$.
	Oxidize graphite at high temperature. Dissolve residue in HNO_3 or HNO_3/HF. Complex fluoride with $Al(NO_3)_3$.
Beryllium (can or alloy)	Dissolution in HCl. Add nitric acid, distil off chloride to give solution in nitric acid. Adjust acidity.
Thorium-based fuels	Dissolution in HNO_3 with fluoride catalyst. Complex fluoride with $Al(NO_3)_3$.

Ion Exchange Processes

Ion exchange, in which the uranium and plutonium are separated from fission products by absorption from aqueous solution on to a solid resin, may be considered as an alternative aqueous separation process, but it shows no overall advantage over solvent extraction and possesses one major disadvantage in that it cannot readily be made truly continuous. Ion exchange processes are, however, widely used for the concentration and purification of plutonium and uranium after fission product removal and also for the recovery of individual fission products or heavy elements from aqueous waste streams.

Volatility Processes

An elegant separation process for irradiated fuel may be based on the recovery of uranium as the gaseous UF_6 (triple point 64.02°C at 1,137 mm Hg). Fluorination of the fuel with fluorine or interhalogen compounds results

in the formation of uranium hexafluoride, which can be distilled away from the solid or liquid residue, which contains the overwhelming majority of the fission products and plutonium as non-volatile fluorides in a greatly reduced bulk. Fractionation of the gaseous product yields extremely pure UF_6 which is suitable for feeding directly to a gaseous diffusion plant for re-enrichment. The degree of decontamination from fission products is comparable to that achieved by solvent extraction, so that ultimate manual refabrication is possible.

Recovery of plutonium from the residue may be achieved by aqueous methods or, under more exacting fluorinating conditions, PuF_6 can be formed and volatilized. In the case of fuels which consist primarily of uranium, the highly active operations subsequent to the removal of UF_6 may be carried out in a very much reduced scale of plant. Thorium fuels are not so amenable since thorium, which forms a non-volatile fluoride, comprises the bulk of the fuel. After separation of the U^{233} (as UF_6) a large-scale highly-active aqueous process would still be required to recover the thorium. When plutonium or thorium recovery is not required the fluoride residue represents a conveniently concentrated form in which to store the fission products.

The process appears most attractive for highly-enriched uranium fuels from which recovery of plutonium is not an economic necessity. In particular, the treatment of zirconium-based enriched uranium fuels (which are not readily amenable to aqueous dissolution) by a route involving fused salt dissolution (Fig. 8) shows considerable technical and economic promise.

The major technological problems concern the handling and containment of the very reactive fluorinating agents in the presence of very high levels of fission product activity. Nevertheless, large-scale laboratory work is reported to have reached a sufficiently advanced stage for construction of pilot plants to be considered in the immediate future. Indeed, for certain types of fuel element it may be true to say that the technology of volatility processing is in a more advanced state than the corresponding aqueous head-end treatment for solvent extraction.

Pyrometallurgical Processes

The exceedingly high fission product decontamination factors achieved by solvent extraction and volatility processes are rendered necessary by the requirements of direct manual refabrication of the fuel elements. The elimination of neutron "poisons" for fuel recycling would be adequately met by much lower decontamination factors. For many types of reactor 90% removal of fission products would be sufficient, but the fuel would then require remote refabrication. In the case of fuels containing a high proportion of fissile material, either U^{235}, Pu^{239} or U^{233}, a large inventory cost is incurred if the fuel stands idle for long periods of radioactive "cooling." If the fuel can be quickly reprocessed and returned to the reactor the savings in inventory costs can be set against the cost of remote refabrication.

A number of relatively simple high-temperature processes (Table 3) which are not sensitive to radiation damage and hence do not require prolonged radioactive cooling of the fuel, are capable of the required degree of purification. Most of them also possess the advantage of retaining the fuel in the metallic state throughout, thus eliminating a number of chemical stages which are necessary in other methods.

The absence of aqueous moderators in these processes also leads to economic gains, since criticality restrictions are less stringent and enriched fuel can, therefore, be processed in higher capacity plants. Fission product wastes occur in a compact form for storage.

Considerable technological problems are associated with the development of suitable plant for handling very reactive materials at temperatures sometimes much in excess of 1,000°C. These problems are certain to be solved, but the plants will not be cheap. Another limitation arises from the necessity to keep to simple fuel element designs

Les Problèmes et l'Importance du traitement chimique pour l'Energie Nucléaire

Les raisons qui exigent un nouveau traitement chimique du combustible irradié sont exposées et on y traite de l'influence d'un nouveau traitement chimique sur la part des frais de combustible dans le coût total de l'énergie nucléaire. Les dangers de la radiation et les considérations de point critique ajoutent en une mesure considérable au coût des installations chimiques pour le traitement du combustible irradié, de sorte que des quantités considérables à être traitées sont requis pour donner des frais acceptables de nouveau traitement par unité d'énergie.

Le développement de nouveaux combustibles conçus de façon à nécessiter des nouveaux traitements moins fréquents pose au chimiste des problèmes nouveaux et difficiles. L'extraction des solvants, les procédés de volatilité et les procédés pyrométallurgiques y sont décrits et discutés en rapport avec leur pouvoir de se conformer à divers types de combustible. En conclusion il est déclaré que l'extraction des solvants continuera à assurer la méthode de nouveau traitement la plus économique et la plus souple pendant encore une bonne période.

Die Probleme und der Wert chemischer Verfahren für die Atomkraft-Verwertung

Es werden die Gründe gegeben, die es nötig machen den bestrahlten Brennstoff wiederholt chemisch zu behandeln, und es wird weiter der Einfluss diskutiert, den jede erneute chemische Behandlung auf den Anteil der Brennstoffkosten im Vergleich zu den Gesamtkosten der Atom-Krafterzeugung ausübt. Bestrahlungsgefahren und Erwägungen hinsichtlich der kritischen Höhe tragen erheblich zu den Kosten bei, die bei der Behandlung bestrahlten Brennstoffes in chemischen Werken entstehen, sodass grosse Mengen erforderlich sind, um annehmbare Werte für die Kosten der wiederholten Behandlung je Krafteinheit zu erhalten.

Die Entwicklung neuer Brennstoffe, die gedacht sind weniger häufige wiederholte Behandlung zu erfordern, stellen den Chemiker vor neue und schwierige Probleme. Extraktion mit Lösungsmitteln, Verflüchtigungs-Verfahren und metallurgisch-thermische Verfahren werden in Bezug auf die Möglichkeit die verschiedensten Brennstoff-Gattungen zu verarbeiten, beschrieben und diskutiert. Es wird der Schluss gezogen, dass Extraktion mit Lösungsmitteln weiterhin wohl das wirtschaftlichste und anpassungsfähigste Verfahren zur wiederholten Behandlung für eine geraume Zeit noch bleiben wird.

Los Problemas y la Importancia de Procesado Químico Para la Energía Nuclear

Las razones que exigen el reprocesado de combustible irradiado son explicadas y también se discute la influencia del reprocesado químico sobre la contribución de los costos de combustible a los costos totales de la energía nuclear. Los peligros de la radiación y las consideraciones de "criticalidad" aumentan grandemente el costo de instalaciones químicas para el reprocesado de combustible irradiado, de modo que se necesita que hayan grandes cantidades a ser tratadas para que resulten aceptables los costos de reprocesado por unidad de fuerza.

La evolución de nuevos combustibles ideados para exigir reprocesados menos frecuentes han creado nuevos y difíciles problemas para el químico. La extracción de solventes, los procesos de volatilidad y los procesos pirometalúrgicos se describen y se discuten en relación a su habilidad para hacer frente a diversos tipos de combustible. Se llega a la conclusión que la extracción de solventes continuará proveyendo el método más económico y versátil por mucho tiempo en el futuro.

to facilitate remote refabrication. At the present time, only cast metal shapes can be considered. Little attention has so far been devoted to the significance of likely ceramic fuel developments in high-temperature processing, or in remote refabrication. The behaviour of thorium-based fuels is also largely unexplored. Finally, the chemical and economic problems of recovering the not insignificant amounts of fissile element wastes do not yet appear to have received the attention they merit.

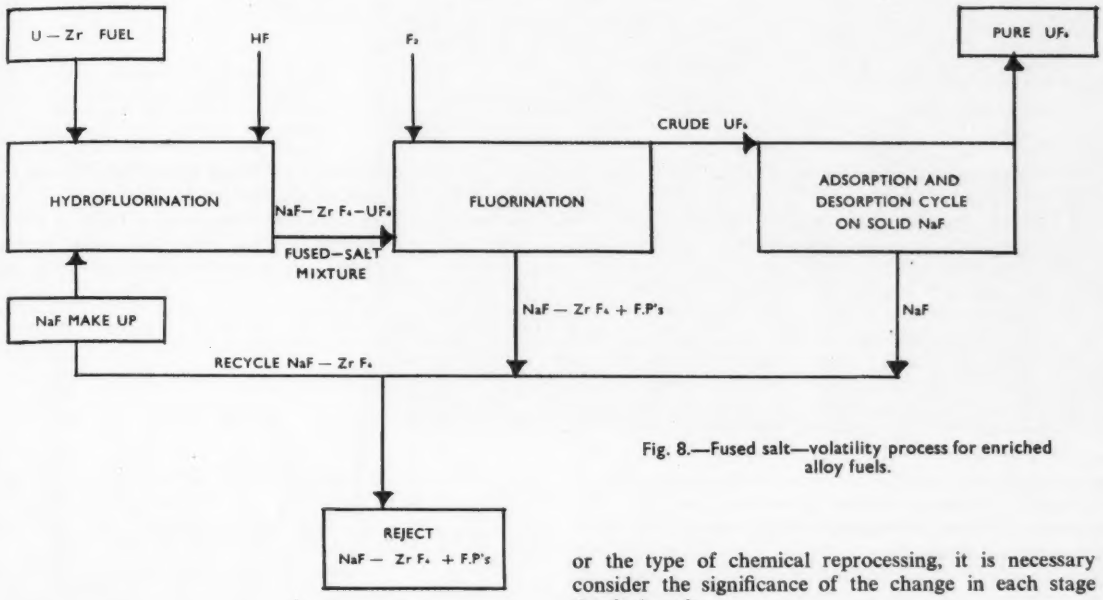

Fig. 8.—Fused salt—volatility process for enriched alloy fuels.

Summary

For maximum economy in use, fuel elements are being designed to withstand higher ratings, higher temperatures and longer irradiation periods. These considerations lead to more chemically intractable fuel in even more chemically intractable outer sheaths. Moreover, fuel element designs for optimum heat transfer characteristics are not readily amenable to mechanical decanning. Additional chemical problems will be created by the presence in the fuel of alloying, diluting or moderating constituents. All this leads to more complex chemical separation problems associated with spent fuel reprocessing. In assessing the economic gain from changes, either in the type of fuel, or the type of chemical reprocessing, it is necessary to consider the significance of the change in each stage of the fuel cycle:

(i) initial fabrication of fuel element;
(ii) irradiation in reactor;
(iii) chemical processing;
(iv) re-enrichment;
(v) refabrication of fuel element.

There is, therefore, every incentive for close collaboration between the reactor designer, the metallurgist and the processing chemist even before a proposed fuel reaches the experimental stage. Ultimately, fuels may be developed which are so long-lived and efficient that reprocessing is not economically justified, but this possibility is not immediate.

In the foreseeable future, solvent extraction is likely to remain the principal method of reprocessing irradiated fuel elements on an industrial scale. Where extremely rapid recycling of highly enriched fuels is required, and the savings to be gained are correctly assessed against the increased costs of, say, high temperature processing and remote refabrication, it is possible that alternative schemes will come into their own, although it has recently been demonstrated that solvent extraction processes are much less susceptible to solvent radiolysis than was hitherto believed.

Owing to the particular problems, capital costs and other fixed charges are higher, by an appreciable factor, than for conventional chemical plant of similar scale. Economic reprocessing therefore demands a high use factor of the facilities, implying a large-scale power reactor system and adequate standardization of fuels.

TABLE 3
Some Possible High-temperature or Pyrometallurgical Processes for the Treatment of Irradiated Fuel

Process	Principles
Volatilization	Melting of uranium enables separation of the rare gas fission products, iodine and the volatile alkali and alkaline earth metals e.g. Rb, Cs, Sr, Ba. Plutonium can also be separated by distillation at temperatures in the region of 1700°C.
Liquid metal extraction	A liquid metal phase immiscible with uranium such as magnesium or silver, can be used to extract certain fission products, and plutonium. Alternatively, a metal (such as zinc) which dissolves uranium but not fission products could be used and afterwards separated from the uranium by distillation.
Oxidative slagging	Controlled oxidation results in the conversion of the more readily oxidized fission product metals to an oxide slag which can be physically separated from the molten uranium. Under mild oxidizing conditions plutonium would not be oxidized. Suitable oxidation can be achieved by melting in oxide crucibles.
Fused salt extraction	Contact with a suitable fused salt may convert the more reactive fission products to salts or compounds which dissolve in the melt and may be separated from the metallic uranium. Plutonium is sometimes oxidized by the melt and then follows the fission products.
Electrolysis	The irradiated metal may be made the anode in a fused salt electrolyte. On electrolysis uranium metal is transferred to the cathode. The more reactive fission products remain dissolved in the electrolyte, some of the more "noble" fission products remain as "anode slime." Under appropriate conditions plutonium metal is also transferred to the cathode.

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The Sub-Critical Facility for MERLIN

To provide physics design data for the Merlin core a versatile sub-critical facility has been built at the A.E.I. Research Laboratories at Aldermaston. The design of this facility provides an elegant solution to the problem of satisfying the requirements of an extensive research programme in absolute safety.

THE essential design parameters of Merlin—the A.E.I. 5-MW research reactor—have been fully discussed by Chick and Salmon in *Nuclear Engineering*, vol. 2, pp. 10-14 and 66-71. The main constructional features of the reactor are now complete and approach to criticality will begin within the next few weeks. A cut-away drawing of the reactor is included in this issue opposite page 200.

Although theoretical calculations can lead to good approximations of the core physics, uncertainties cannot be eliminated and it is almost impossible to make reliable provision for such irregularities as the control element gaps. An experimental determination, therefore, of the magnitude of disturbances is highly desirable and to this end, a sub-critical facility has been built at Aldermaston. The term sub-critical implies that the system is never allowed to diverge, information being obtained from the magnitude and distribution of the neutron flux initiated by a priming source and multiplied by the fissile material. If the reactivity of the core is k where $0<k<1$, the multiplication factor M equals $1/1-k$. The critical mass can thus be extrapolated from reading taken of M against loading. The recorded value of M will be a function of the position of the detector and several runs are necessary to determine the appropriate location of the neutron counters.

The system allows the effect of experimental voids, the temperature coefficient, the efficiency of the control rods, etc., to be assessed, and fine structure flux measurements can be made by foils inserted in the core.

It should be noted that in any series of experiments the initial measurements are taken with the maximum reactivity expected in the series built in, to prevent an inadvertent excursion into criticality. For example, in the initial stages, to check safety element effectiveness, a safety element can be motored into the core but not out. Strict fuel control is also practised to eliminate the possibility of excess loading. Tests on control elements are made with clamped elements which cannot be removed with the core moderated.

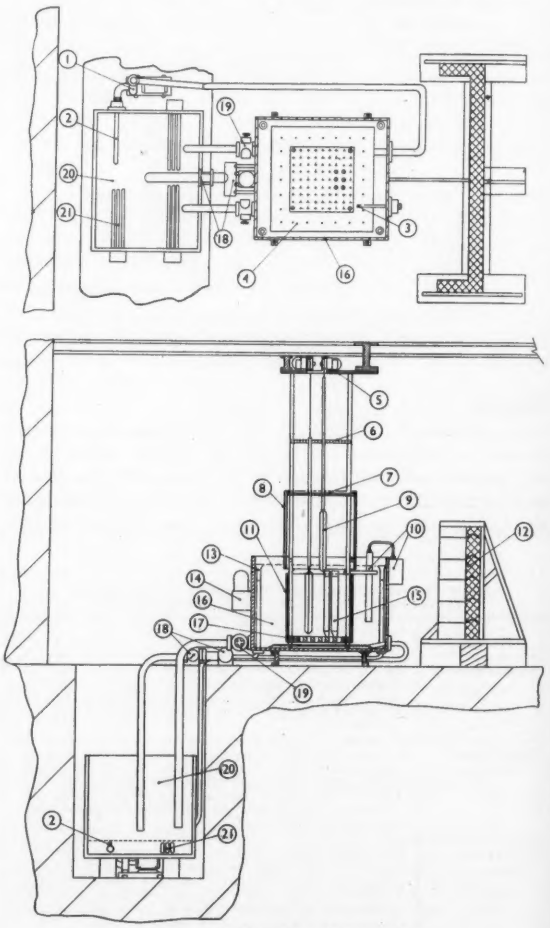
Under typical operating conditions reactivity is set at $k=0.998$. M is thus 500 which gives a power level of approximately 1 mW. This corresponds to a maximum neutron flux at the centre of the core of 10^4 n/cm², sec.

The detailed discussion of the design of the equipment which follows is taken from a report prepared by Burden, Caesar and Kerridge of the A.E.I. Laboratories.

Water System

As demineralized water is to be used in the reactor, it was decided that this should also be employed for sub-critical experiments, in order to avoid the possibility of starting incipient corrosion of the fuel elements. The materials of the water system have been chosen accordingly; copper and its alloys, being particularly deleterious, have been avoided altogether.

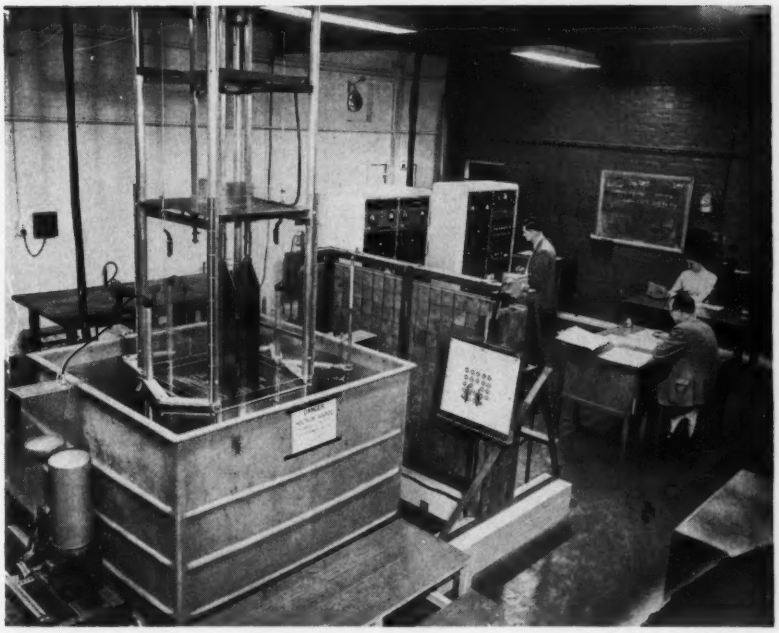
The main features of the water system can be seen from the outline diagram of the equipment given in Fig. 1. The main or core tank has dimensions 5 ft x 4 ft 6 in. x 3 ft 9 in. high and is made of a glass fibre/epoxy resin laminate known as "Resilon." It is provided with two 3-in. bore



Plan and elevation of the unit.

KEY

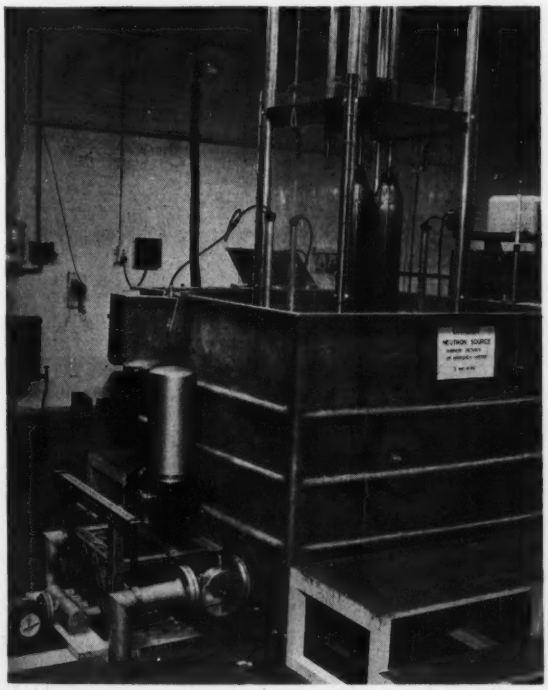
1. Pump and non-return valve.
2. Dump tank thermostat.
3. Core tank thermostat.
4. Jet plate.
5. Motor frame.
6. Upper guide frame.
7. Lower guide frame.
8. Core lid.
9. Safety element.
10. Neutron counter and head amplifier.
11. Core box.
12. Lead wall.
13. Overflow pipe.
14. Gamma ionization chamber.
15. Fuel element.
16. Core tank.
17. Lattice plate.
18. Manifold and flow indicator.
19. Dump valves.
20. Dump tank.
21. Heaters.



(Right) General view showing the arrangement of the laboratory. (Below) A view of the facility showing the gamma ionization chamber and dump valves at the LH side of the core tank.

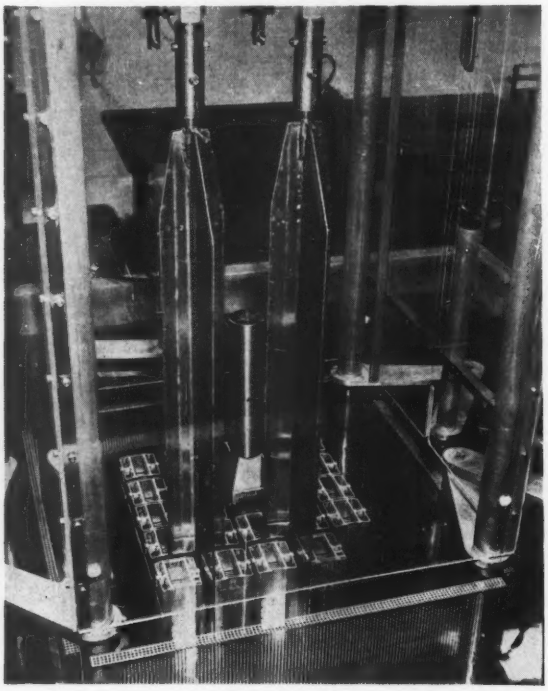
pipe flanges close to the bottom of each end face and four 2-in. bore flanges at each corner of the base. The dump tank is similar to the core tank except that it has no flanges in the base. It is situated in an 8 ft deep pit in the floor of the building and has a hardboard cover.

When filled to normal level, i.e., with about 6 in. of water above the active part of the fuel elements, the core tank holds 450 gal. It is filled from the dump tank by a stainless-steel centrifugal pump which has a capacity of 35 gal/min, i.e., 1 in. rise for every 20 sec. The water rises, via a non-return valve, through 2-in. i.d. p.v.c. tubing and enters the tank through numerous holes in a jet plate which is part of a shallow box forming a false bottom to the tank. The water level is set by four aluminium overflow pipes at the corners of the tank. These are connected by p.v.c. tubing to a manifold which returns the water to the dump tank via a flow-indicator and switch. The core tank is provided with a simple glass-tube water-level gauge not shown in the diagram.



In the top tank a 3-in. bore dump valve with a 3-in. pipe draining directly to the lower tank is fitted to each of the two flanges at the end nearest the pit. It was not possible to obtain suitable commercial valves, owing to the unusual requirements for materials and method of operation, and special ones had to be designed. They are of a simple butterfly type, being closed manually but retained by an electromagnet and armature acting against a heavy counter-weight. Since they constitute one of the main safety features of the equipment, they are designed for certain opening when the electromagnet current is interrupted. In the closed position, the two valves together have a leak of about 1 gal/min (1 in. in water level per 10-15 min); when both are open the tank empties at an initial rate of 350 gal/min (1 in. per 2 sec).

Heating of the water is provided by three inconel-sheathed immersion heaters, all in the dump tank, with a total loading of 18 kW. Each heater has three separate 2 kW elements arranged for 3-phase working. A heater control unit allows each heater to be separately switched by mercury relays either "off," "on," or "automatic." In the last position, the heater is controlled from one of two thermostats which are fixed in the dump tank and core tank respectively. The choice of thermostat is made automatically so that when all the water is in the dump tank the thermostat in that tank has control. Thus, for example, the temperature of the water can be maintained overnight at the desired value so that no time will be lost at the beginning of the working day. To raise the temperature of the water from 15°C to 55°C takes about eight hours. Switching on the pump automatically makes the dump tank thermostat inoperative and removes power from the controlled heater or heaters. When the core tank is full,



Close-up view showing fuel elements and safety rods.

the flow switch operates and brings the core tank thermostat into action. There will always be enough water in the dump tank to cover the heaters adequately. Putting the heaters in the dump tank instead of in the main tank has two advantages: more experimental space is available, and the continuous circulation of water should give a reasonably uniform temperature without the need for the mechanical stirring that would otherwise be necessary. Water temperature is measured by long stem mercury-in-glass thermometers in protective stainless steel tubes.

Demineralized water for filling the system is readily available locally. No water treatment is provided on the equipment; if the purity should become unacceptably low the whole charge will be replaced. A reserve of 100 gal of demineralized water is provided in an asbestos tank.

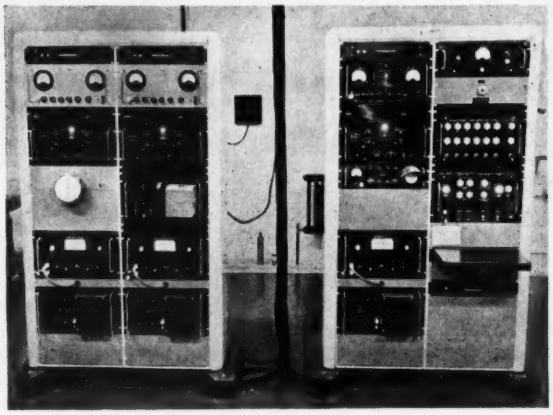
Mechanical Arrangement

The mechanical part of the sub-critical apparatus consists essentially of a structure to support the core of fuel elements and also the safety elements together with their associated drive motors, magnetic clutches and cable drums.

The fuel elements stand in a lattice plate which is a duplicate of that used in the actual reactor, except that it is made of commercially pure aluminium instead of a special alloy. Perforated aluminium sheets are attached to the support tubes at each side of the lattice plate to act as a screening box. This is purely a safety measure and, in conjunction with the core lid described later, makes it impossible to add fuel or make adjustments to the core without raising the lid. It is proposed to make some experiments to study the effect on critical mass of a reactor beam tube close to the core. To do this, one side of the screening box will be replaced by a plate carrying a horizontal closed cylinder simulating a beam tube. The plate will remain in position during the series of experiments and will not impair the effectiveness of the screening box.

The lattice plate is suspended by four 2-in.-diameter aluminium tubes from an upper motor frame which is fixed to steel joints in the roof of the building. At the lower end, the structure is steadied by the tubes being located in holes in the false bottom of the tank.

Two safety elements identical to those in the reactor, are attached to square-section Duralumin support rods which slide in guide blocks. The latter are positioned on upper and lower guide frames forming part of the superstructure. Each safety element can be raised or lowered independently by a cable attached to its support rod through a shock-absorbing device. The cable winds on a drum which is driven by a geared motor through an electromagnetic clutch-coupling. A safety element falls into the core by gravity when the current to its clutch is interrupted. The guides are made from Bakelite and the drums designed



Neutron counter racks.

so that less than a complete turn of cable is needed; at the same time their inertia is kept as small as possible and they are mounted on roller bearings. It should be noted that the two safety elements are quite separate both mechanically and electrically.

When dropped by the magnetic clutches, the lowest position of the safety elements is set by the cable lengths. The range of travel under motorized control is determined by limit switches actuated by the support rods. The limit switches, besides controlling the drive motors, also act as interlocks in the control and safety circuits.

Another pair of support rods and guides is provided. These are not motorized but, on the contrary, are arranged to be firmly clamped in any desired vertical position. The clamps are inside the core lid.

The core lid, mentioned earlier, consists simply of a four-sided box, open top and bottom, made from "Perspex" sheet. It is fitted with pads sliding on the four support tubes so that it can be raised and lowered manually by means of a cable and winch. Limit switches arranged inside the lid are operated when it is in the lowest position. The lower guide frame is made so that with the core lid in this position there is no access to the core.

Neutron Counting Equipment

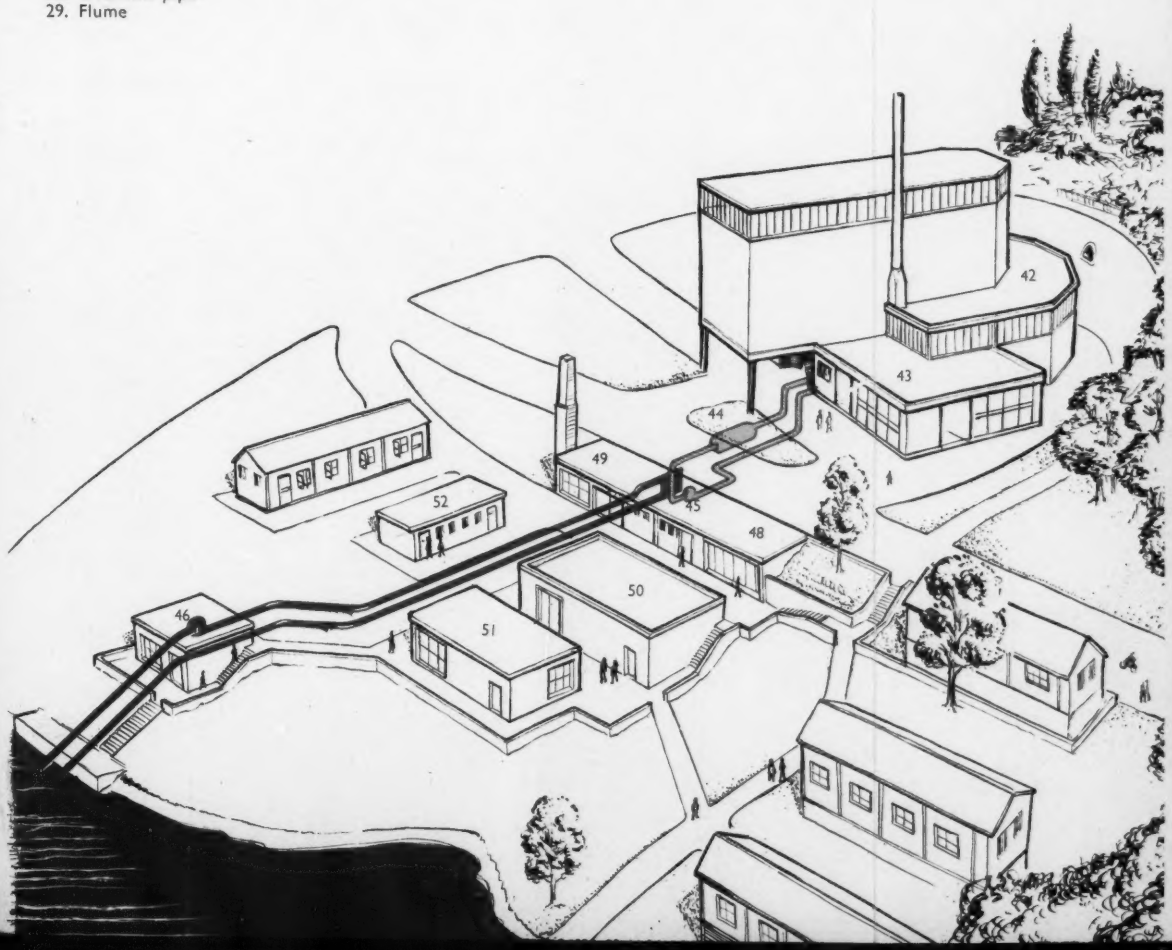
The priming source is polonium-beryllium, dimensions 13 mm by 8.5 mm dia., emitting $1\text{-}3 \times 10^6$ n/sec (the emission falls off with a half-value period of 138 days). The source is fitted in a hole near the centre of the lattice plate.

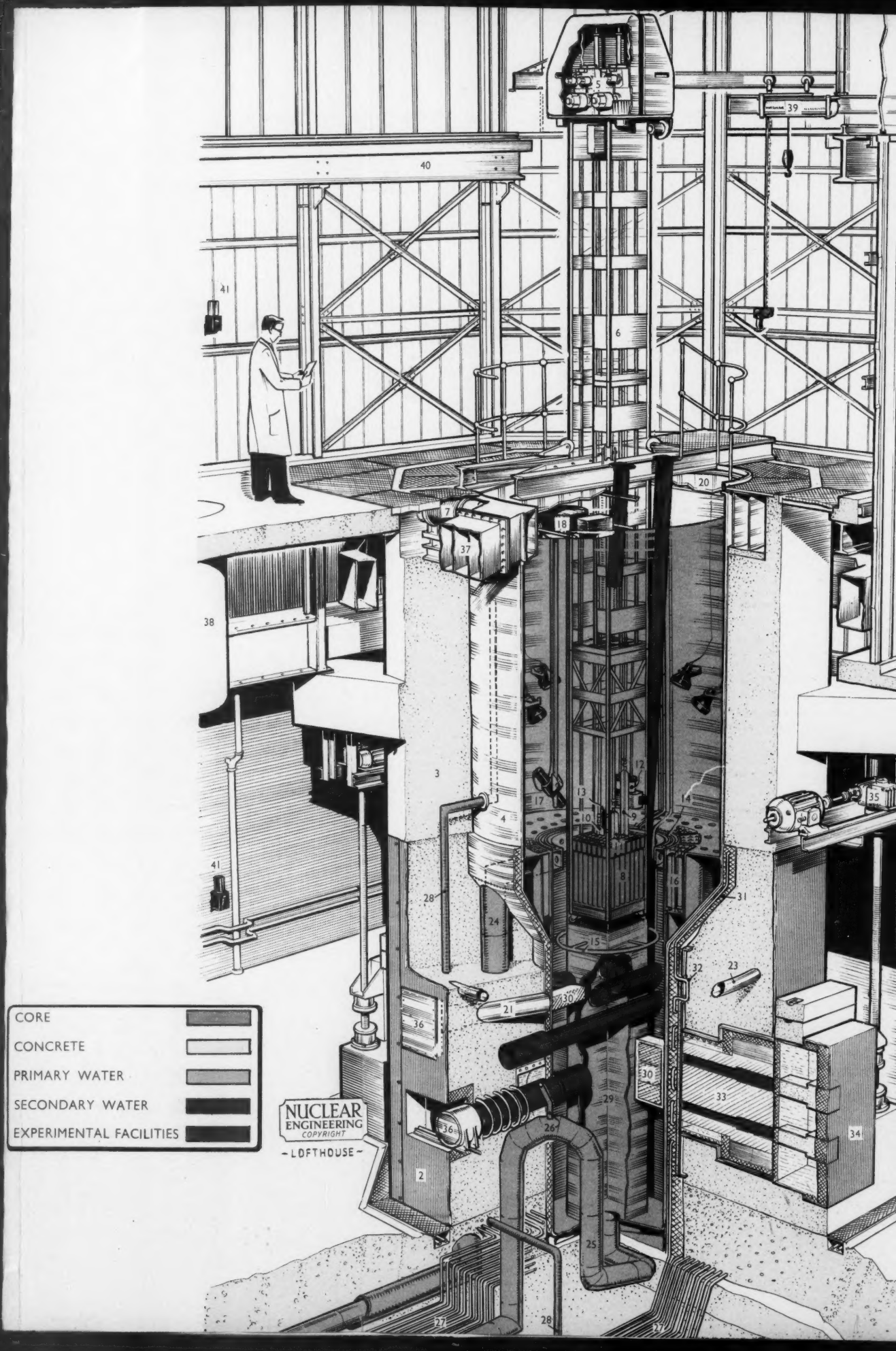
The World's Reactors

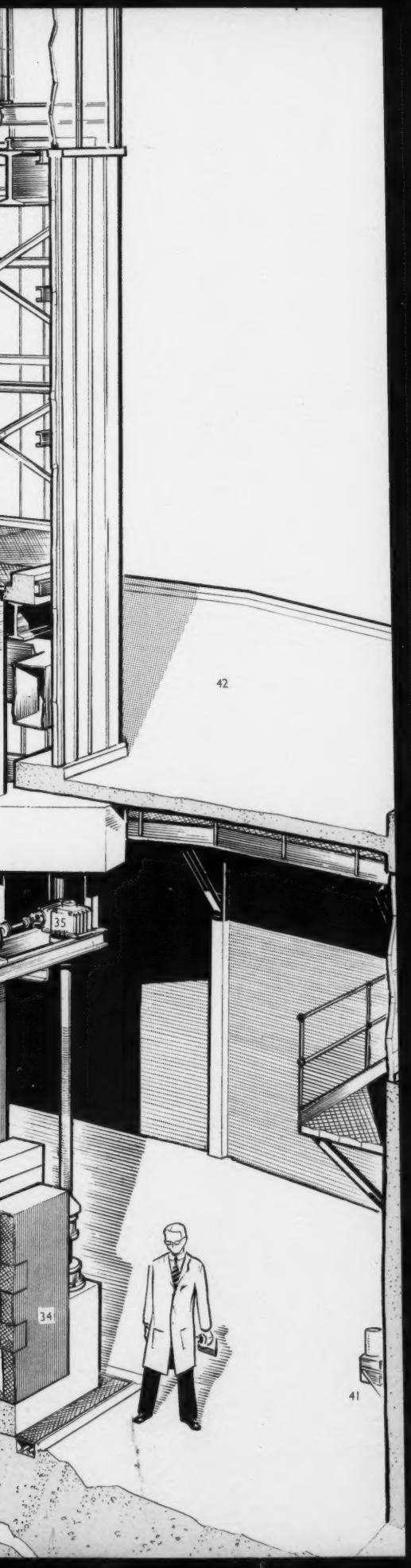
No. 17 MERLIN

KEY

1. Experimental area
2. Steel outer casing
3. Biological shield
4. Reactor tank
5. Control-rod motors
6. Core structure
7. Core hoist winch
8. Core in loading position
9. Fine control rod
10. Coarse control rod
11. Shut-down rods
12. Ionization chamber
13. Fission chamber
14. Core spray
15. Feed to fission product detector
16. Fuel element storage compartments
17. Underwater television camera
18. T.V. camera manipulator
19. Chemical tubes
20. Perspex cover
21. Ion tube
22. Experimental facilities
23. Air suction ring main
24. Feed water inlet pipe
25. Feed water outlet pipe
26. Anti-syphon tube to top of tank
27. Cooling water pipes
28. Overflow pipe
29. Flume
30. Graphite nose pieces
31. Thermal shield
32. Thermal shield cooling pipes
33. Thermal column
34. Thermal column door
35. Door-raising mechanism
36. Removable covers
37. Air extract duct
38. Wash-down tank for upper floor
39. Fuel element handling hoist
40. Travelling crane track
41. Health monitor
42. Reactor building
43. Control room
44. Delay tank
45. Primary pump house
46. Secondary pump house
47. Lake
48. Make-up plant house
49. Boiler house
50. Sub-critical facility and fuel element store
51. Effluent treatment plant
52. Change room




CORE
CONCRETE
PRIMARY WATER
SECONDARY WATER
EXPERIMENTAL FACILITIES
NUCLEAR ENGINEERING
COPYRIGHT
-LOFTHOUSE-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The World's Reactors

No. 17 MERLIN

TYPE:	Pool, with four-position core.
PURPOSE:	Research, testing, education and training.
LOCATION:	Aldermaston, England.
OWNER:	A.E.I., Ltd.
CONSTRUCTION:	A.E.I.—John Thompson Nuclear Energy Co., Ltd.
RATING:	5 MW maximum.
FUEL:	Uranium, 93% U^{235} (initial charge), future charges, lower enrichment. 20/80 (wt.) U–Al alloy, Al clad. Minimum critical investment: 2.67 kg U^{235}. Normal investment: 3.5 kg U^{235}.
ELEMENTS:	MTR type: 14 plates per box. Critical loading: 20 elements minimum. Active length 23.6 in. Box dimensions: $2\frac{7}{8}$ in. × $2\frac{7}{8}$ in.
LATTICE:	Up to 49 elements in square array. 3-in. pitch, $\frac{3}{8}$-in. gap between rows for control and safety elements.
MODERATOR:	Light water. Reflector: light water or beryllia.
REACTIVITY:	Maximum: 5.5% δk excess.
FLUX:	At core centre, water reflected, 5 MW power: Epithermal neutron, 2×10^{14} n/cm², sec. Thermal neutron, 5×10^{13} n/cm², sec. γ, 4×10^{8} r/h.
PRIMING:	Sb—Be source on each element.
CONTROL:	S.S. sheathed Cd, cruciform shape; Two safety units: −5.5% δk each, Coarse unit: −5.5% δk. S.S. strip, $1\frac{1}{4}$ in. × $\frac{1}{8}$ in.; Fine unit: −0.5% δk.
DRIVE:	Coarse: constant-speed motor, in and out, gravity, spring-assisted in event of trip. Fine: variable-speed motor, in and out. Coarse travel time: 25 min to full out. Min. fine travel time: 25 sec to full out.
COOLANT:	Light water. Primary flow: two 800-gal/min electric pumps, one diesel-driven pump; max. total flow: 1,900 gal/min. Delay tank: 100 sec. Max. temp.: 45°C. Primary purification bleed: 1,000 gal/h filtered, 150 gal/h ion exchange. Secondary flow: two 900-gal/min pumps.

MAIN TANK: High-purity aluminium, $\frac{3}{8}$-in. thick, sunk 2 ft 3 in. below floor level. Dimensions: 16 ft 3 in. × 5 ft 6 in. dia. widening to: 13 ft 9 in. × 11 ft 6 in. dia.

SHIELDING: Lead thermal shield 4 in. thick encased in Al. Barytes concrete 3.5 g/cm³ for first 15 ft, ordinary concrete above. Thickness: 6 ft $1\frac{1}{2}$ in. to 10 ft 9 in. above floor, 3 ft 6 in. to top.

FACILITIES: Top position: fuel changing. Upper exptl.: see table. Lower exptl.: see table. Bottom position: storage.

Experimental Facilities

Type	Dimensions	Plane	Number	
			Upper	Lower
Thermal column	4 ft 6 in. × 4 ft 6 in. × 6 ft	Horizontal	2 (one removable)	0
Holes in thermal columns	4 in. × 4 in. × 6 ft	Horizontal	7	0
Hole in centre of core	3 in. × 3 in. × 24 in.	Vertical	1	1
Vacant lattice positions	3 in. × 3 in. × 24 in.	Vertical	50 max.	50 max.
Through-holes tangential to core	6 in. i.d.	Horizontal	0	2
Shelf	1 ft 6 in. × 1 ft 6 in.	Horizontal	0	1
Holes stopped at lattice	12 in. i.d.	Horizontal	1	0
	6 in. i.d.	Horizontal	3	4
	3 in. × 6 in.	Vertical	0	2
γ-radiation facilities	3 in. × 3 in. × 24 in.	2	20 max., in fuel storage bays	

Data sheets in this series already published in "Nuclear Engineering" are:

No. 1. *BEPO* (*April*, 1956)
No. 2. *CP5* (*May*, 1956)
No. 3. *NRX* (*June*, 1956)
No. 4. *DIMPLE* (*August*, 1956)
No. 5. *ZEUS* (*September*, 1956)
No. 6. *CALDER HALL* (*October and December*, 1956)
No. 7. *RUSSIAN 5 MW* (*November*, 1956)
No. 8. *DIDO* (*January*, 1957)
No. 9. *THE SOUTH OF SCOTLAND ELECTRICITY BOARD STATION* (*February*, 1957)
No. 10. *BERKELEY POWER STATION* (*March*, 1957)
No. 11. *BRADWELL POWER STATION* (*April*, 1957)
No. 12. *DOUNREAY FAST REACTOR* (*June*, 1957)
No. 13. *EBWR* (*July*, 1957)
No. 14. *RWE* 1 (*September*, 1957)
No. 15. *LIDO* (*November*, 1957)
No. 16. *PLUTO* (*April*, 1958)

General view of the laboratory from behind the lead brick radiation screen.

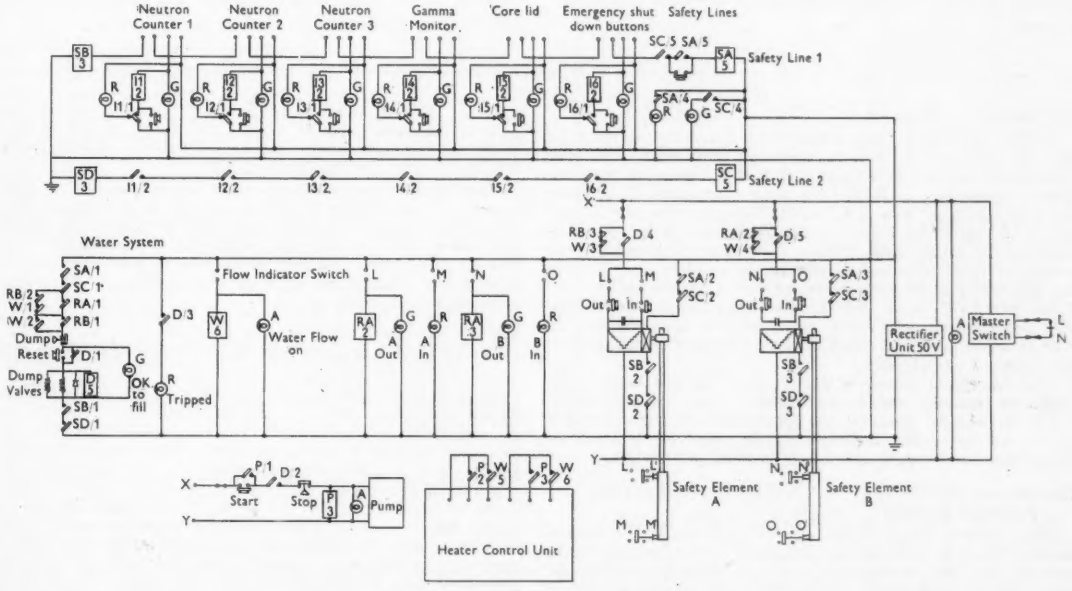
The neutron detectors are BF_3 proportional counters—three being used normally. They are placed near three sides of the core in aluminium tubes supported on adjustable brackets which can be firmly clamped in the position found best for any particular experiment. Each counter is connected by a short cable to its own head amplifier which is fixed to the lip of the tank under a protective cover. Cables from the head amplifiers are taken off to the main counting equipment.

The main counting equipment is contained in three sections of two double-width 6 ft racks, the control equipment occupying the other section. Each of the three neutron counting channels consists of an EHT unit to supply a stable high voltage to the counter, a pulse amplifier, a scaling unit, a ratemeter and a trip unit. In addition, there is a single timing unit which can be used to control all the scaling units, individually or in common, to make accurate measurements of the number of counts recorded in a given time interval. The ratemeters provide a continuous indication of the mean neutron counting rate in each channel. They are used to observe the changes in counting rates with water level during the filling of the core tank and, in conjunction with the trip units, give an automatic shut-down if the rates exceed pre-selected values.

Control System

As far as practicable, the circuits have been arranged so that attempted operation of the apparatus except in a predetermined sequence is prevented, rather than causing a subsequent shut-down and hence loss of time.

The experimental procedure for which the control and safety circuits are designed is briefly as follows. Loading of fuel into the lattice plate or any adjustment affecting the core is made with no water in the core tank. Before water can be added, all the shut-down instruments must be giving a "safe" indication and the two safety elements must be raised out of the core. This being so, water can be pumped into the tank to give a moderated core. From a safety aspect, this is the crucial stage in the procedure, since it is



Control and safety circuit diagram.

Fuel storage rack with locks to prevent element removal.

during this operation, and during this operation only, that a possibly dangerous situation could arise if, by a gross error, an excess of fuel had been loaded. In such a case, the shut-down instruments operate to drop the safety elements into the core, switch off the pump and open the dump valves. However, this situation ought never to occur and normally the tank fills up to the level of the overflows. Experimental observations of neutron counting rates are then made. After completing the observations, a controlled shut-down is made in which water is emptied from the main tank.

Safety Circuits

Fig. 2 shows the control and shut-down circuit and its connections to other parts of the system.

There are two safety lines. Each of these consists of two relays connected in series across a 50 V supply. Two relays were used so that even if a short-circuit fault should develop in the wiring, only one of the relays could be permanently energized. Between the relays, contacts from all shut-down instruments are connected in series. Each instrument has two sets of normally open contacts, one of which is connected directly in safety line 1 (relays SA and SB shown in Fig. 2). The other set controls a relay (I1 to I6 respectively) which operates a contact in safety line 2 (relays SC and SD). Thus, there are two independent electrical paths which can cause shut-down; this occurs when any of the four relays is de-energized. The relays I1 to I6 control an indication system showing the state of the particular instrument and of safety line 2.

Supply of Fuel

The total amount of U^{235} fuel at the Laboratory during the time of sub-critical experiments will be 4.47 kg, made up of 31 full elements (140 g each) and 4 partially full elements (10, 20, 40, 60 g respectively). The fuel elements are stored in racks in steel cupboards, each fuel element being individually locked in position. A set of rules to ensure the safe custody of the fuel has been drawn up but from a safety aspect, the important rule is that which lays down that fuel will be issued only to the person responsible for the experiments and only to an extent authorized by the Reactor Sub-Section Leader. The amount of fuel made available will be decided after careful consideration by the Sub-Section Leader and will not be more than the quantity required for the experimental work in progress at the time.

The facility has now been in operation for nine months and has proved to be of the greatest value in preparing for the Merlin project.

La Facilité Sous-Critique de Merlin

Une facilité sous-critique a fourni des données expérimentales pour la construction finale du noyau qui sera employé dans le Merlin—le réacteur de recherches de 5 MW représenté en coupe dans ce numéro. La facilité est placée aux côtés du réacteur qui a été construit par A.E.I.-John Thompson Nuclear Energy Co., Ltd., aux Laboratoires de Recherches de l'A.E.I. à Aldermaston. Le noyau sous critique à essayer est monté sur un treillis, de forme identique à celui qui est employé dans Merlin, à l'intérieur d'un réservoir en résine epoxy à fibres de verre de 1,524 *m*×1,370 *m*×1,142 *m. De l'eau déminéralisée peut être pompée dans le réservoir pour modérer le noyau et peut être vidangée par des tuyaux de grand diamètre contrôlés par des soupapes magnétiques.*

Une conception soignée et la prévision d'une instrumentation suffisante assurent qu'un essai doive suivre un programme prédéterminé. Le contrôle du combustible et des couplages pour empêcher toute augmentation de réactivité pendant un essai font en sorte que le système ne devienne pas critique.

Einrichtung im „Merlin" zu Prüfungen vor Erreichen des kritischen Punktes

Es ist beim „Merlin," dem 5 MW-Reaktor für Forschungszwecke, Vorsorge getroffen worden, um, bevor der kritische Punkt erreicht wird, auf experimentellen Wege Daten zu erhalten, die dann bei der endgültigen Konstruktion des Reaktors, der in diesem Heft in einem Teilschnitt dargestellt ist, zugrunde gelegt werden sollen. Die Prüf-Einrichtungen sind neben dem Reaktor angeordnet, der von der A.E.I. und der John Thompson Nuclear Energy Co. Ltd. in den A.E.I. Forschungs-Laboratorien in Aldermaston gebaut worden ist. Der Kern, der unterhalb der kritischen Grösse geprüft werden soll, ist auf einem Gerüst montiert, das in der äusseren Form dem gleich ist, das beim Merlin benutzt wird, und zwar im Inneren eines aus Glasfaser mit Epoxy-Harzen hergestellten Tanks von 1,524×1,37×1,42 *m. Wasser, dem alle Mineralien entzogen worden sind, kann in den Tank gepumpt werden, um als Moderator im Kern zu dienen und kann durch weite Rohre abgeleitet werden, wobei Magnet-Ventile zur Steuerung dienen.*

Sorgfältige Konstruktion und volle Ausrüstung mit genügend Instrumenten gewähren Sicherheit, dass jedes Experiment nach einem genau geplantem Programm ausgeführt wird. Brennstoff-Kontrollen und von einander abhängige Verriegelungen verhindern jede Vergrösserung der Reaktivität während eines Experimentes und schützen das System davor, dass die Reaktivität kritische Grösse erreicht.

Facilidad para Comprobación de Núcleos Sub-Críticos en el Reactor " Merlin "

Una facilidad subcrítica ha provisto datos experimentales para el diseño final del núcleo que será usado en el " Merlin "—el reactor de investigaciones de 5 MW—ilustrado gráficamente en forma descubierta en este número. Dicha facilidad se halla localizada a lo largo del reactor que ha sido construído por A.E.I.-John Thompson Nuclear Energy Co. Ltd., en los Laboratorios de Investigaciones de la A.E.I. en Aldermaston. El núcleo subcrítico a ser eomprobado está montado en una placa de celosía, idéntica en forma a la que se emplea en el " Merlin," dentro de un tanque de resina " epoxy " de fibra de vidrio de 5 *pies*×4 *pies* 6 *pulgadas*×3 *pies* 9 *pulgadas* (1,524 *m.*× 1,370 *m.*×1,142 *m.*). *Se puede bombear dentro del tanque agua desmineralizada para moderar el núcleo, cuya agua puede ser vaciada a través de tubos de diámetro interno grande con control por válvulas magnéticas.*

Un diseño esmerado y la provisión de una instrumentación adecuada asegura que un experimento tiene que seguir un programa predeterminado. Control del combustible y cierres combinados de seguridad durante un experimento aseguran que el sistema no se vuelva crítico.

Petroleum Lubricants

—*Their Application in Nuclear Plant*

Lubrication in nuclear plants cannot be eliminated. This article reviews the general application of petroleum-based oils and greases to meet the arduous conditions imposed by radiation, and the suitability of certain types of lubricant.

By C. H. NAILER, A.M.I.Mech.E.
(Industrial Power Plant Lubrication, Shell-Mex Ltd.)

THE application of hydrocarbon oils in the nuclear energy industry is proving to be far greater than at first anticipated; this is becoming increasingly evident as work proceeds on new designs for research and power projects.

The lubrication requirements of nuclear power stations can be divided into two categories, conventional or standard, and special where radiation and high temperature and certain other factors are involved. In nuclear power stations now being constructed a large proportion of the plant, e.g. the steam turbo generators, can be lubricated with modern additive-type oils. Similar oils are suitable for lubricating the bearings of motors or turbines driving the gas-circulating blowers, on power reactors, but many blower designs incorporate oil seals, for which lubricants having special properties are required.

These oils must possess the oxidation stability and anti-corrosion properties of conventional high-quality turbine lubricants but, most important of all, they must have extremely low vapour pressures and low gas-solubility characteristics, since the lower the vapour pressure at the working temperature, the less likelihood there is of oil vapour escaping into the gas system.

At the oil/gas interface in a seal, some gas will be taken up by the oil, the amount depending on the solubility coefficient. This varies widely with different gases and oils, although with CO_2 and a carefully selected blower oil, the volume ratio of gas absorbed/oil circulating through a seal, at a given pressure, would be of the order of 1 : 3. Much of the gas can be extracted by reducing to normal atmospheric pressure the oil flowing from the seal, and any CO_2 remaining in the system will have no detrimental effect on the oil in circulation. It is therefore practicable, in the majority of designs, to employ a common oil system serving the seals and main bearings of the blower shafts and driving motors, and to return oil from the detraining system to the main tank.

Blower lubricants are not normally subjected to radiation and the performance can be expected to compare favourably with that of modern turbine oils.

In practice it is essential that the oil used in gas-circulating systems be maintained entirely free from impurities, and to achieve this a regular programme of centrifuging is advisable. This factor is important, because insoluble impurities, such as dust or scale, may affect the efficiency of the seal. Also, excessive moisture may give rise to corrosion, particularly in the presence of dissolved carbon dioxide, although this is prevented to a large extent by the inhibitors present in high-quality blower lubricants.

Radiation and Petroleum-based Lubricants

Much has been written in recent years about the effects of radiation on various substances, and some results have been published on experiments carried out to determine changes which occur in hydrocarbon and synthetic lubricants when subjected to neutron or gamma activity.

Crude petroleum obtained from scattered producing centres varies in composition, and this is reflected in the molecular structure of lubricating oils manufactured from these basic materials.

(a) Lubricating Oils. Examination of a wide range of hydrocarbon oils has revealed considerable variation in their resistance to radiation, some solidifying after receiving a given dosage, while others remain fluid at the same radiation level. This is illustrated in Fig. 1. It has been established that neutron, gamma or electron activity produces similar changes in physical characteristics of hydrocarbon oils, the effect therefore depending not upon the type of radiation but the total energy absorbed. Briefly,

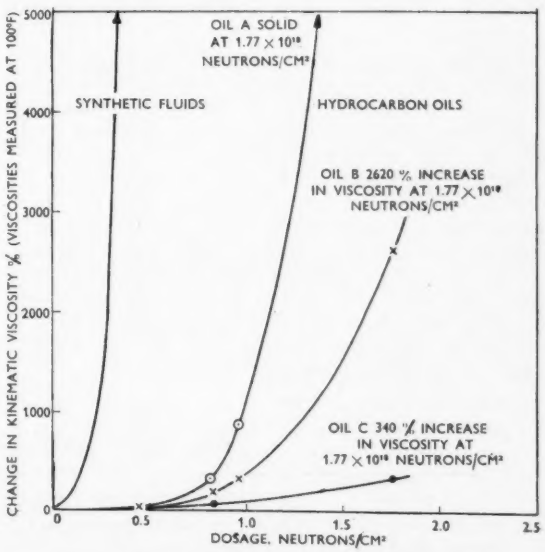


Fig. 1.—Effects of radiation on hydrocarbon oils and synthetic fluids.

radiation accelerates the process of polymerization due to displacement of hydrogen atoms by the energy particles and subsequent cross-linking of the molecules. These changes are revealed initially by an increase in viscosity and, if the oil is subjected to a sufficiently high radiation dose, gelling will occur, followed eventually by solidification. Mineral oils containing relatively high proportions of aromatic material, or those of low molecular weight, possess superior radiation-resistance, and products of this type now form the basis of lubricating and hydraulic oils which can be employed in machinery operating under radiation.

The useful life of a lubricant under radiation can be estimated, from this aspect alone, on the average intensity of activity. For example, some mineral oils suffer only slight damage when subjected to a total pile dosage of 10^{18} thermal neutrons/sq. cm (plus associated radiation), the equivalent effect being obtained with gamma radiation up to 10^9r (or 1,000 Mrad). Hence, if one of these oils is employed in mechanisms subjected to gamma radiation averaging 10^5 r/h, the useful life can be expected to exceed 10,000 hours.

An important point to be considered, however, is that oils of high radiation resistance usually have relatively low oxidation stability. While it is possible to improve this feature by incorporating inhibitors, oxidation and its consequences may prove to be a limiting factor on performance, particularly if the lubricant is operating at elevated temperatures in the presence of oxygen.

In many applications relating to gas-cooled reactors where machinery is subjected to radiation, bearings, etc., are situated within the gas system, and this, of course, virtually eliminates the oxidation problem. Under such conditions the lubricant should function satisfactorily without attention or replacement for considerable periods, provided precautions are taken to prevent contamination or loss by leakage.

Radiation resistance of hydrocarbon oils is, in general, superior to that of many synthetic lubricants which may be used in normal circumstances, and the use of the latter is, therefore, ruled out for machinery operating under radiation. For optimum performance it is necessary to ensure that operating conditions are well within the capabilities of the hydrocarbon lubricant, since the use of well-known additives is impracticable, mainly because of the physical and chemical changes which occur, and induced radio-activity from interaction with neutrons, which may create difficulties and delays in servicing equipment. Alternative methods of enhancing the natural properties of hydrocarbon lubricants without the use of metallic compounds are under active investigation.

(b) Greases. Special greases have been developed in recent years for nuclear power plant operating at high temperatures and subjected to radiation.

There are many applications in power reactor equipment, some of which are mentioned in the following pages, where grease lubrication of components has already been proved by practical experience to have many advantages over other methods of treatment. Grease in an anti-friction bearing, for example, provides a seal against the entry of dirt and extremely good protection against corrosion, a factor of great importance, particularly before commissioning and during the initial run-up of the reactor.

Earlier experiments, results of which have already been published, show that conventional greases based on metallic soaps, e.g. lithium, calcium and sodium, suffer rapid radiation damage, due initially to breakdown in the soap structure, resulting in liquefaction. If the oil used in the grease is of low aromatic content and, consequently, of low radiation resistance, the liquid phase will be followed, as mentioned earlier, by gelling and eventual solidification

The special greases, on the other hand, retain their original structure and consistency under radiation for at least six times as long as conventional greases, and suffer no damage when subjected to a total integrated pile dosage of at least 2×10^{18} thermal neutrons/cm^2 (plus associated radiation). They are, moreover, non-reactive with CO_2, whereas metallic soap-based greases are adversely affected by CO_2 under pressure, particularly at high temperatures.

The main factors limiting the life of a grease are oxidation and radiation, but in many applications, e.g. anti-friction bearings, etc., the lubricant would be used permanently, or for a proportion of its period in service, in inert atmospheres, conditions under which it is less temperature-sensitive, and replacement would be required less frequently.

Applications

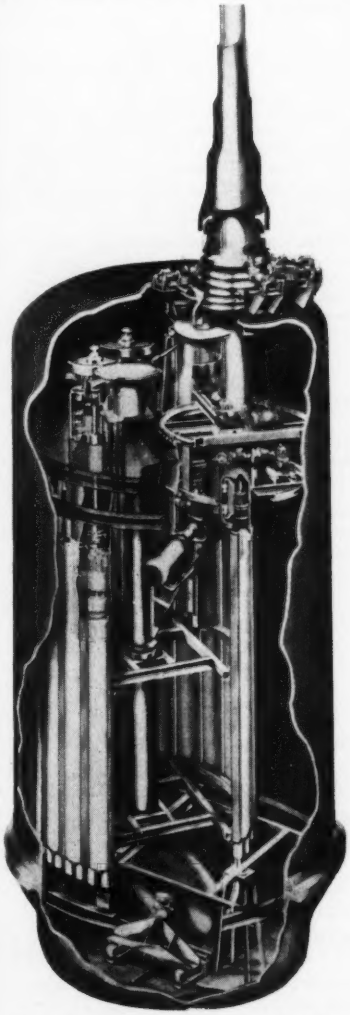
A summary of typical applications for radiation-resistant lubricants is shown in Table 1, together with details of conditions which may be encountered in practice.

(a) Control Gear. There are many different designs of equipment for controlling the output of a reactor, and most of these incorporate gear transmissions running in grease-lubricated anti-friction bearings. In the case of the gas-cooled system, the winch mechanism is continually operating in an inert atmosphere and is subjected to temperatures perhaps as high as 200°C, and also neutron and gamma radiation. In some designs, the gear trains are

Table I.—Applications of Radiation-resisting Lubricants

Application	Components	Operating conditions		Lubricant
		Temperature	Radiation	
Reactor control equipment	Ball or roller bearings Gears	150°C max. (CO_2)	Gamma	Grease : Shell A.P.L. 700
Reactor charging and discharging machines	Ball and roller bearings	150°C (CO_2)	Neutron gamma	Grease : Shell A.P.L. 700
Gas circulating blowers	Seals Bearings	80°C max.	None	Oil : Shell A.P.L. 729
Remote handling equipment	Gears (spur) Gears (worm) Ball bearings	Ambient Ambient Ambient	Gamma Gamma Gamma	Oil : Shell A.P.L. 734 Oil : Shell A.P.L. 710 Grease : Shell A.P.L. 700
Hydraulic systems	Oil system	Ambient	Gamma	Oil : Shell A.P.L. 742
Burst slug detection equipment	Ball bearings	100°C (CO_2)	Gamma	Grease : Shell A.P.L. 700
Rotary compressors	Bearings and gears	200°C (inert atmo.)	Gamma	Oil : Shell A.P.L. 734
Valves	Spindles	80°C (CO_2)	Negligible	Grease : Shell A.P.L. 700

sealed within a housing and can, therefore, safely be grease-lubricated. Where the gears are exposed to the circulating gas, it is essential that no lubricant be applied, mainly to avoid contamination of the gas or the possibility of some of the lubricant finding its way down into the reactor core. For exposed gears, therefore, it is sometimes considered desirable to apply special surface treatments in order to prevent scuffing or undue wear of the gear teeth.



Fuel element charge-discharge machine. (Courtesy General Electric Co. Ltd.)

It is generally considered desirable to grease-lubricate the anti-friction bearings in reactor control units and, in fact, this offers many advantages over other suggested methods of treatment. Experience has shown that it is necessary to fit each bearing into its own individual housing and not to expose the bearing or the lubricant to the hot gas. Such precautions prevent the grease being contaminated or thrown out of the bearing and it also almost eliminates loss by evaporation.

If space does not permit the use of conventional housings, sealed bearings with close fitting shields on either side can be employed. In view of the high temperatures likely to be encountered in these applications, it is necessary to use all steel bearings since yellow metal cages can act as a catalyst and affect the life of the lubricant.

(b) Charge-discharge Machines. This equipment, like the control gear, may incorporate gear trains running in anti-friction bearings and driven by electric motors. The mechanism operates a drum on which is wound the cable fitted with a grab for hoisting spent fuel elements from the reactor core. Charging and discharging at Calder Hall is carried out with the reactor shut down, but with the C.E.G.B. power stations, charging operations will take place with the reactor at full power. Consequently, as soon as the charge machine is located over one of the charge tubes, the pressure chamber within the machine will fill with hot gas and the mechanism will be subjected to gamma and, perhaps, some neutron activity. In many cases it is anticipated that the temperatures will not exceed about 200°C, and the radiation will most likely be sufficiently low to ensure reasonable life of the bearing and gear lubricants.

The grab mechanism, which is lowered into the reactor core, will obviously be subjected to conditions far too severe for any hydrocarbon lubricant, but the movement of links and hinge pins, etc., is such that lubrication by conventional means is unnecessary.

Fuel-charge machines of somewhat different design, though still incorporating gear trains mounted in anti-friction bearings, are employed in reactors cooled with liquid sodium. This type of mechanism can also be lubricated successfully at moderate temperatures (around 150°C) with suitable radiation-resistant greases which have been developed for this purpose.

Remote-controlled Equipment

Slave Manipulators. The operating mechanisms of small manipulators are designed largely to avoid the use of conventional lubricants, though it is sometimes found necessary to employ grease-lubricated, sealed anti-friction bearings for rotating sleeves and joints. The sealed bearing has a long service life without attention, and the lubricant provides protection against corrosion and ensures low frictional resistance.

In some of the larger installations, i.e. process plant cells, power manipulators* are used, driven electrically or hydraulically, and the drive is through trains of gears which can be arranged for oil lubrication. The same grade of lubricating oil would be suitable for the gearbox bearings, and splash lubrication would probably be the most convenient unless other factors justify the installation of a pump and pressure oil-feed system.

Bearings other than those situated within the gearbox are grease-lubricated, though some of the small, lightly loaded bearings may require no lubricant at all. Hydraulic fluids used for such applications must be sufficiently resistant to radiation to remain in service for fairly long periods without deterioration. At the same time, as with conventional machinery, it is of advantage for the oil to possess enhanced anti-corrosion properties. Oxidation stability is of less importance where systems are completely filled with oil and no vented reservoir is provided.

Conclusions

Lubrication is an important factor in the efficient operation of nuclear power stations and related equipment. In the development of products for the many special applications, problems have arisen which are not encountered in other engineering fields.

For example, selection of materials used in the manufacture of oils, additives and greases is restricted to products which are compatible with the coolant and acceptable in close proximity to the reactor. Irradiation of many components of conventional lubricants results in the formation of objectionable by-products and may give rise

* See p. 207.

to difficulties in maintenance or disposal of waste. Such materials have been avoided and, where possible, trace impurities are removed.

Extensive laboratory tests and the field experience gained over the past few years now show that it is possible to produce lubricants which meet many of the exacting requirements in this type of plant.

Nevertheless, lubricants of any type have their limitations and their successful use depends largely on the design of a satisfactory system and, in practice, strict adherence to fundamental rules in regard to application, cleanliness, filtration, grease-packing of bearings, and storage, etc. Provided these rules are followed, satisfactory service is assured.

Reference

David, V. W., and Irving, R. "Effects of radiation on hydrocarbon oils, greases, and some synthetic fluids." Conf. on Lubrication and Wear, Oct., 1957. *Chartered Mech. Eng.*, to be published.

Les Applications des Lubrifiants à Base de Pétrole dans les Installations d'énergie Nucléaire

Dans les centrales nucléaires, un grand nombre d'applications conventionnelles des lubrifiants, par exemple, les machines à turbines, se prêtent à l'emploi des lubrifiants conventionnels. Pour d'autres applications, cependant, des lubrifiants possédant des propriétés spéciales sont essentiels.

Les huiles minérales contenant des proportions relativement élevées d'aromatiques, ou celles dont le poids moléculaire est bas, possèdent une résistance à la radiation d'ordre supérieur et la durée des produits de ce type est très longue. Certaines huiles minérales qui ne sont que peu atteintes par une radiation aussi élevée que 10^{18} neutrons thermiques/cm² donneront des durées utiles pouvant atteindre 10.000 heures, si on les emploie sous une radiation gamma d'une moyenne de 10^5 R/heure. Des huiles de ce type, cependant, possèdent d'habitude une stabilité d'oxydation relativement basse, et il est nécessaire d'y veiller si elles doivent être employées dans de l'air à des températures élevées.

Des graisses spéciales ont été mises au point pour parer au désagréments qui se présentent lors de l'emploi des graisses conventionnelles basées sur les savons métalliques, qui aboutissent à une liquéfaction et, éventuellement, à la gélification et la solidification. L'article comprend une vue d'ensemble d'applications typiques auxquelles des types particuliers de lubrifiants conviennent.

Die Verwendung von Mineralölen als Schmiermittel in Atom-Kraftwerken

In Atom-Kraftwerken kann für viele konventionelle Anwendungen, z.B. für Turbinen-Anlagen, die Schmierung mit konventionellen Schmiermitteln durchgeführt werden. Bei anderen Anwendungen sind jedoch Schmiermittel wesentlich, die gewisse spezielle Eigenschaften haben.

Mineralöle, die einen verhältnismässig hohen Prozentsatz aromatischer Bestandteile enthalten oder solche von geringem Molekular-Gewicht, besitzen einen hohen Widerstand gegen Bestrahlung, und Produkte dieser Art sind von langer Haltbarkeit. Einige Mineralöle, die nur wenig unter einer Bestrahlung von einer Höhe bis zu 10^{18} thermischen Neutronen pro cm² leiden, weisen sogar eine Haltbarkeit von 10.000 Stunden auf, wenn verwendet unter einer Gamma-Strahlung, die im Durchschnitt 10^5 R/Stunde beträgt. Oele dieser Art besitzen jedoch meistens eine verhältnismässig geringe Stabilität gegen Oxydierung und Vorsicht ist daher geboten, wenn sie in Luft bei höheren Temperaturen Verwendung finden.

Spezielle Schmierfette sind entwickelt worden, um die Schwierigkeiten zu vermeiden, die bei den konventionellen Fetten entstehen, die auf Metallseifen basieren, und die zur Verflüssigung führen und schliesslich zur Gelbildung und zur Erstarrung. Der Aufsatz enthält eine Uebersicht über die typischen Anwendungen, für die die verschiedenen Arten von Schmiermitteln besonders geeignet sind.

La Aplicación de Lubrificantes de Petroleo en Plantas de Fuerza Nuclear

En las centrales de fuerza nuclear, muchas aplicaciones convencionales de lubrificantes, es decir, maquinaria de turbinas, pueden ser llevadas a cabo con lubrificantes convencionales. Para otras aplicaciones, sin embargo, son esenciales lubrificantes con características especiales.

Aceites minerales conteniendo proporciones relativaelevadas de "aromáticos" o aquellos de bajo peso molecular, poseen superior resistencia a la radiación y productos de este tipo tienen larga duración. Algunos aceites minerales que sufren poco daño a causa de radiación tan elevada como 10^{18} neutrones térmicos por centímetro cuadrado, tendrán una duración útil tan elevada como 10.000 horas, si se emplean bajo una radiación gamma con un promedio de 10^5 R/hora. Sin embargo, los aceites de este tipo generalmente tienen una estabilidad de oxidación relativamente baja, y es necesario tener cuidado si van a ser usados en el aire a temperaturas elevadas.

Se han ideado grasas especiales para contrarrestar los contratiempos que ocurren con las grasas convencionales basadas en jabones metálicos, que resultan en liquifracción y, a las largas, gelatinización y solidificación. El artículo incluye una revista de las aplicaciones típicas para las cuales hay tipos específicos de lubrificantes que son convenientes.

Heavy-Duty Power Manipulator (*see opposite page*)

Un Manipulateur de Puissance pour Gros Travaux

On croit que le manipulateur développé par A. C. Wilson and Partners est le plus puissant en son genre qui existe. Il fut développé à l'origine pour la manutention des boucles expérimentales et possède une capacité de soulèvement de plus de 1.000 kgs. Il est actionné hydrauliquement et est en mesure d'accomplir des mouvements longitudinaux et transversaux, et un mouvement vertical d'environ 2 mètres, avec une rotation continue de la tête de fonctionnement. Bien qu'il soit en mesure de saisir avec une très grande force, la limitation automatique pourra être prévue de sorte que des tubes à parois minces pourront être maniés sans dégâts. Un nombre de têtes interchangeables pourront être prévues et il y a des prises de mouvement pour l'actionnement des outils ou machines.

Maschinell allseitig bewegliche Greifvorrichtung für schwere Lasten

Die Greifvorrichtung, die von „A. C. Wilson and Partners" entwickelt worden ist, dürfte die grösste ihrer Art sein, die zur Zeit existiert. Sie war ursprünglich dafür entwickelt worden Abzweig-Leitungen für experimentelle Zwecke zu handhaben und sie hat dazu eine Hubkraft von mehr als 1000 kg. Sie hat hydraulischen Antrieb und kann längs und quer bewegt werden, hat einen senkrechten Hub von ungefähr 2 m, und der Greiferkop, kann dabei dauernd nach allen Richtungen gedreht werden. Trotz der Fähigkeit einen sehr starken Klemmgriff auszuüben gewährt der Greifer die Möglichkeit, durch eine selbsttätige Begrenzung des Griffes auch dünnwandige Rohre ohne Beschädigung zu handhaben. Es sind eine Anzahl auswechselbarer Greiferköpfe vorgesehen und Abzweigungen für Kraftantriebe für Werkzeuge und andere maschinelle Einrichtungen.

Manipulador a Maquina de Servicio Pesado

El Manipulador diseñado por A. C. Wilson & Partners es, según creemos, el más potente de su clase en el mundo. Se desarrolló originalmente para manejar "loops" (lazos) experimentales y tiene una capacidad de izada de más de 1.000 kilos. Es mandado hidráulicamente y puede moverse tanto en sentido longitudinal como transversal con movimiento vertical de aproximadamente 2 metros, con rotación continua en la cabeza operadora. Aunque es capaz de un agarre extraordinariamente fuerte se le puede dotar de limitación automática para que los tubos de paredes frágiles puedan ser manejados sin causarles avería alguna. También se puede suministrar cierto número de cabezas intercambiables, y hay disponibles mandos de toma de fuerza para mandar herramientas o máquinas.

A Versatile Heavy-duty POWER MANIPULATOR

By J. A. MARSH
(*Divisional Manager and Chief Engineer (Nuclear, Mechanical and Chemical Division) A. C. Wilson and Partners, Ltd.*)

British-manufactured power-operated manipulators for exceptionally heavy duty are already in operation at the Windscale and Dounreay establishments of the U.K.A.E.A. In this article, the author describes the philosophy of design, and outlines their capabilities.

THIS manipulator was originally developed by the author's company to meet the need for remote handling of bulky, heavy and complex experimental liquid-cooled fuel element loops after irradiation in DMTR. In addition to handling considerably greater loads than had previously been contemplated, it was required that the manipulator should be versatile and capable of performing a wide variety of comparatively heavy-duty machining operations.

General Considerations

The concept is original, since it was felt that any configuration based upon the human arm might suffer from inherent multi-joint complexities and provide difficulties in obviating lost motion or sponginess, particularly whilst ensuring ample strength for handling very large loads without recourse to undue bulk.

For this reason, the designers decided at the outset to divorce any "wrist" motion from the main body, and incorporate this feature as an integral part of separate heads when specifically required. The provision of a comprehensive range of remotely and automatically interchangeable heads or tools (including horizontal and vertical box spanners, drilling heads, single and double motion jaws, slitting and grinding tools, etc.) should ensure the widest possible field of application; it was felt that the heavy tasks could be safely undertaken with simple, robust implements, and the more delicate and intricate operations performed with more flexible devices whilst maintaining "feel" and fine control over movements whether the duty be light or heavy.

At such an early stage in the development of the DMTR Cave and its experimental hot loops, it was extremely difficult, if not impossible, to formulate a realistic specification, and it was appreciated that the slavish adherence to purely theoretical requirements could result in unnecessarily high costs and a protracted delivery. The feasibility study was, therefore, based upon:—

(1) The desirability of scanning the largest plan area within a given building, thus requiring longitudinal and transverse motions similar to those of an overhead travelling crane.

(2) The provision of a telescopic "trunk" of maximum stroke and rigidity when fully extended to floor level or at any point of thrust or power application.

(3) Continuous clockwise and anti-clockwise rotation of the telescopic assembly, and

(4) The provision at the lower extremity of the telescopic assembly of at least one and preferably two power take-off drives to operate a range of implements or tools.

(5) An accurate and reasonably sensitive means of simple manual control capable of duplication at several "stations" or windows.

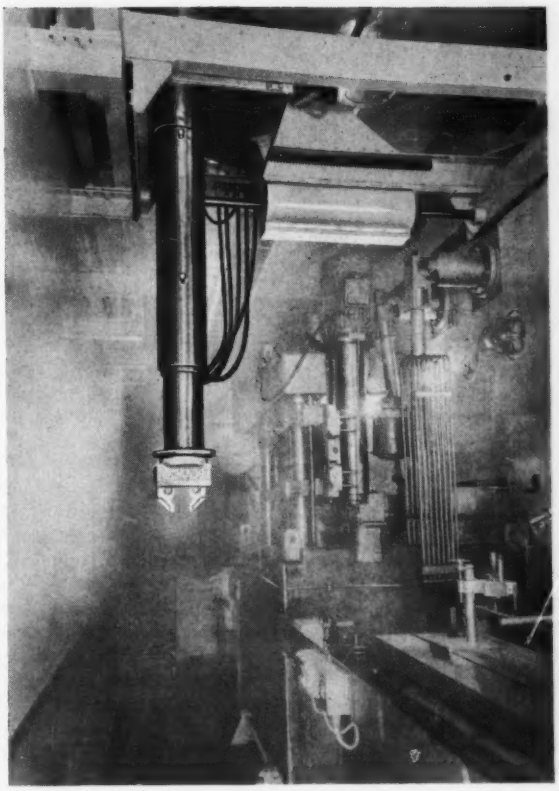


Fig. 1.—A "Wilson" manipulator in operation in the Irradiated Fuel Element Laboratory at Windscale. A similar unit is installed in the DMTR "Cave" facility.

(6) Compact power units with good low and zero speed torque characteristics.

(7) Ability to withstand prolonged exposure to high-level gamma sources, coupled with the minimum of maintenance and lubrication.

(8) Robust, reliable and compact construction.

(9) Adequate automatic overload protection.

(10) Clean contours to minimize alpha and beta contamination, and smooth, durable finishes to resist corrosion and assist in decontamination.

Having regard to the above factors, a study was undertaken of the alternative power sources, i.e., electrical, pneumatic, or hydraulic, and the various possible combinations. As a result, the U.K.A.E.A. accepted the recommended use

of hydraulic units, provided that a virtually leak-proof system could be devised.

Basic Mechanical Construction

The manipulator consists essentially of a carriage of the requisite width to span a given building, positively driven along a pair of longitudinal tracks of the required length, and providing transverse track along which a trolley member may be positively traversed. A continuously rotatable body formed by a circular table with integral trunk is mounted on, and projects downwards through, the centre vertical axis of the trolley by means of a pair of large-diameter opposed Timken taper bearings. Attached to this body is the vertical telescopic tube or arm assembly.

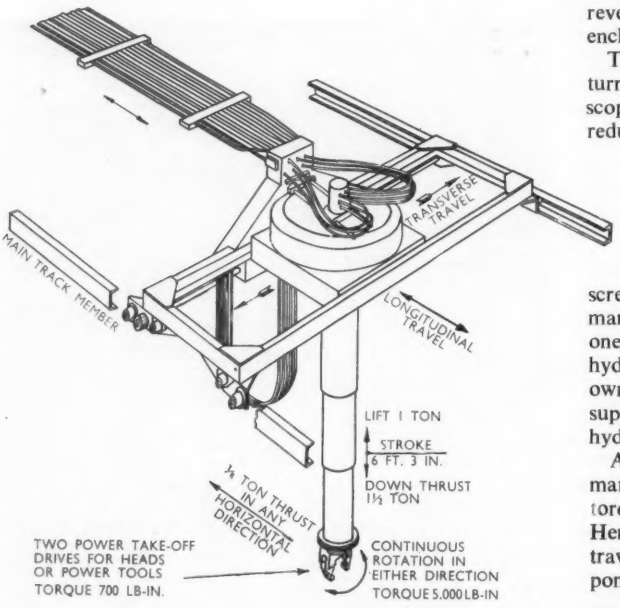

MAIN TRACK MEMBER
TRANSVERSE TRAVEL
LONGITUDINAL TRAVEL
LIFT 1 TON
STROKE 6 FT. 3 IN.
DOWN THRUST 1½ TON
⅛ TON THRUST IN ANY HORIZONTAL DIRECTION
TWO POWER TAKE-OFF DRIVES FOR HEADS OR POWER TOOLS TORQUE 700 LB-IN.
CONTINUOUS ROTATION IN EITHER DIRECTION TORQUE 5,000 LB-IN

Fig. 2.—Outline of unit showing movements.

Fully enclosed within the telescopic tube assembly are two telescopic power take-off drive shafts which extend and retract with the main outer tube assembly, the whole being rotatable in either direction on the vertical axis. These two drives terminate, at the base of the lowest telescopic tube, in the form of square section projections, to which various implements may be attached by remote means.

Both the carriage and the trolley are supported upon four flanged rollers which rest upon the lower flanges of the tracks and are fitted with sealed anti-friction bearings. Adjustable upper reactive rollers engage the upper flanges of the tracks and prevent tilting laterally and longitudinally when horizontal tractive effort or force is being applied by the telescopic tube assembly.

Propulsion of both carriage and trolley is effected (via suitable reduction units) by means of a balanced torque cross-drive shaft carrying a pair of pinions which mesh with racks secured to the track webs. These racks are arranged in a shrouded position, with the teeth projecting downwards.

Motions and Basic Movements

The basic motions or possible movements (without powered attachments or implements) are shown in Fig. 2, and are briefly as follows:—

Longitudinal and transverse horizontal travel enabling, within reason, any size of plan area to be scanned.

Vertical movement of the telescopic tube assembly enabling objects to be lifted from floor level with a stroke of 6 ft 3 in. Continuous clockwise or anti-clockwise rotation of the complete telescopic tube assembly, thus enabling objects to be turned in plan through 360°.

The power take-off drives can be continuously driven simultaneously or singly in both clockwise and anti-clockwise directions. In addition, of course, further motions can be obtained by the use of single or double motion heads driven from the two power take-offs.

Individual Drives

Individual gear-type hydraulic motors are used to drive each moving element or motion, since they are easily reversible, do not require brakes, are very compact, totally enclosed and self-lubricating.

Three such motors are mounted upon, and, therefore, turn with, the rotating body. One raises and lowers the telescopic tube assembly via a totally enclosed oil bath type reduction unit coupled to primary and secondary telescopic screws mounted wholly within the main tube assembly. The manipulator will, therefore, automatically sustain a load of one ton without the use of a brake, even in the event of a hydraulic failure. Each of the other two motors drives its own power take-off. There are six motors in all. The supply to the rotating body is taken by means of a 13-way hydraulic slip-ring assembly.

All the structural and mechanical components of the manipulator are stressed to withstand safely the full output torque of the motors at the limit of any particular travel. Hence, if by accident any motion reaches the limit of its travel at maximum power and speed, all the relevant components are protected by means of a hydraulic relief valve.

Performance

The Manipulator will

(a) Lift a load of 2,240 lb or 1 ton from floor level (relatively minor modifications will enable the manipulator to lift loads up to 3 tons without any increase of input power or change in motor size);

(b) Exert a downwards thrust of 1½ tons;

(c) Exert a force of ⅛ ton in any direction parallel to the floor with the telescopic tube assembly fully extended;

(d) The manipulator body and tube assembly can provide a turning force or moment of 5,000 lb-in. about its vertical axis;

(e) Each power take-off will give an output torque sufficient (via a box spanner head) to shear the head off a ½-in. dia. Whitworth bolt.

Power Link

The question of whether the prime movers, i.e., electric motors driving hydraulic pumps, should be mounted directly on to the manipulator or outside the building did not arise in either the DMTR cave or the I.F.E. laboratory, since there was insufficient headroom available to accommodate them, and they were, of course, mounted outside.

Since each motor is reversible, it requires separate lines returning to its control valve, each line serving alternatively as pressure inlet and return.

The manipulator is, of course, movable in relation to

the hydraulic pump or pumps, and the supply of fluid between the former and a distribution board mounted centrally above, on one side member of the transverse carriage, is by means of high-pressure reinforced flexible hoses. The inlet and return hoses, together with the common bleed line, are clamped at intervals between slats with anti-friction shoes, which are supported by and move in guide rails secured closely to the roof of the building.

On leaving the working area these hoses pass through a duct terminating in a simple gravity take-up cabinet, located in the Maintenance Area. Both the duct and cabinet form an integral part of the general air-conditioning system, and thus clean air, drawn into and through both the cabinet and duct prevents the outward passage of any airborne radioactivity.

From the distribution board metal pipes supply fluid to the carriage drive motor. Similarly both the trolley and rotating head motors are fed via flexible hoses, the latter two moving linearly with regard to the distribution board and thus presenting no real problem.

The virtual elimination of oil leaks has received great attention and each hydraulic motor shaft is fitted with two oil seals, separated by an annular low pressure space. Any oil leaking past the inner seal is thus bled off to a common point and returned to the reservoir outside the building. This principle is also used on the hydraulic slip-ring.

Remote Control

The control system is the essence of simplicity in that the operator relies solely upon movements of the hand and can devote his undivided attention to viewing the task being performed.

Each movement or motion has its own lever mounted at convenient heights in a console located below each operating window, of which there are three on the DMTR Cave, and four on the Irradiated Fuel Element Laboratory. Each set of controls is duplicated at each " Station " or window and a simple mechanical interlock is provided to prevent inadvertent use by anyone other than the operator. Within reasonable engineering limits and provided the manipulator can be adequately viewed, either directly or by closed circuit television, the controls can be located some distance away from the actual operations to be performed. In contrast to the master-slave type of light duty manipulator, there is no mechanical linkage between the machine and its control console, the only connections being self-reeling hydraulic hoses in guides close to the ceiling where they cannot interfere with operations.

Each control lever is spring loaded into a vertical neutral or " deadman's handle " position to which it automatically returns upon being released. Movement of the lever towards the operator will, for example, move the manipulator towards the operator, an away movement giving the opposite effect.

The hydraulic control system incorporates a servo device which automatically feeds back a proportion of the effort exerted by the manipulator to the operator's handle, thus providing him with " feel."

The effort applied by the manipulator is thus proportionate to the effort applied by the operator until full torque or speed is reached at the lever's limit of travel.

The various mechanical reductions have been carefully matched with the torque-speed curves of the hydraulic motors. This, allied to the valve and control lever characteristics, provides an infinitely variable control over speed of movement plus extreme ease and accuracy of " inching." Control tests by inexperienced operators have shown that loads of 1 ton can be placed in a desired position with an accuracy of thousandths of an inch.

Types of Head Available

Combined vertical and horizontal power-driven box spanners up to ½-in. capacity, incorporating automatic torque-limiting device giving preferentially greater torques for releasing nuts.

Power-driven and overload-protected single motion lifting jaws with a range of 1 in. to 7 in. to lift 400 lb.

Double-motion lifting jaws accommodating a range of tube sizes from 2 in. to 7½ in. without changing the jaws and incorporating overload protection to lift 120 lb. This head does not require accurate positioning in relation to the objects to be grasped since the jaws have self-centring characteristics.

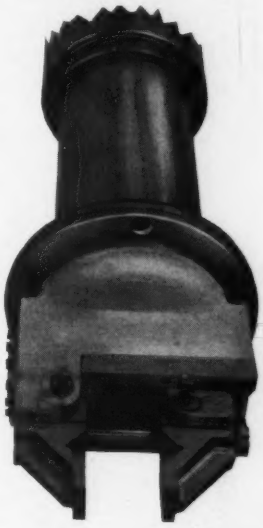


Fig. 3.—Detail of jaw-type head.

The double motion feature enables horizontal objects to be lifted and then turned through 90° to a vertical position or any desired intermediate position, any position throughout this range of movement being self-sustaining.

One-ton lifting head, and a range of power drills, grinders, slitters, etc.

Head Changing

For the DMTR cave, a multi-head table was designed, which, when not in use, is hydraulically retracted into a wall recess, thus providing an unimpeded working area.

To effect a change of head or tool, the telescopic tube assembly is located over the particular head required, is then lowered until contact is made, rotated through 30° and then withdrawn vertically again with the head now securely attached. The coupling between the tool drive mechanisms and the power take-off drives is automatically effected at the same time. Removal of a head or implement and the substitution of another is the reversal of the foregoing procedure.

Maintenance, Lubrication and Decontamination

By careful attention to detail design, greasing points have been reduced to one only, and a grease resistant to the effects of gamma radiation is used (see Nailer, C. H., " Petroleum Lubricants," pp. 203-206). Well protected or sealed anti-friction and self-lubricating bearings are used extensively. Screws and gears receive an anti-flux treatment to assist in running-in.

The exterior contours are smooth and clean, the telescopic tube assembly being hard chromium plated, whilst the whole of the upper components are totally enclosed above and below by detachable stainless steel covers, thus enabling the manipulator to be washed down.

Acknowledgments

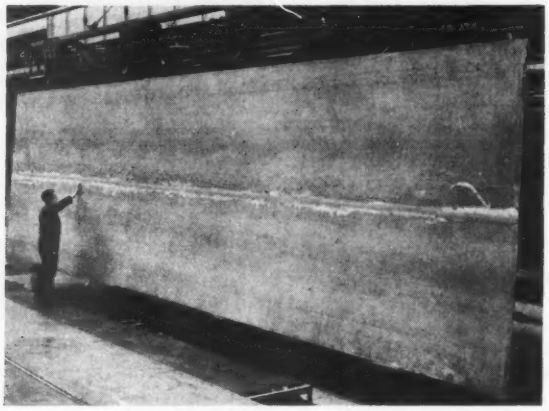
The author wishes to acknowledge the co-operation of the E.R.D.O., and Commercial branches of the U.K.A.E.A., the sub-contractors, and also thank his engineering colleagues, Messrs. L. Bates and D. Humphreys, for their efforts.

For translations see p. 206.

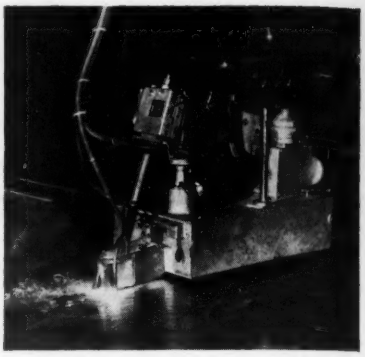
Wide Aluminium Plate Production

New Facilities at Rogerstone

THE ability to obtain aluminium plates in large sizes is a matter of considerable interest to all industries utilizing aluminium fabrication. New equipment at the Rogerstone (Mon) mills of the Northern Aluminium Co. Ltd. will not only enable plates as large as 11 ft wide by 30 ft long to be supplied, but will enable alloy plates to be supplied in a fully heat-treated state, free from internal stresses that would cause buckling during machining, and cut squarely to size within much closer limits than have hitherto been possible.



(Left) An example of the size of plate produced.



(Right) The Argonaut automatic welding head.

Through the courtesy of the company, we have been able to visit Rogerstone and inspect the latest additions, which represent an investment of some £500,000; part of an expansion scheme totalling nearly £10m, of which £8m is scheduled for new plant and buildings. Rogerstone has, already, of course, one of the most modern continuous strip mills in the country, which was opened in 1950; a major portion of the future expansion scheme will take the form of a new 12 ft hot mill. Wide plates are, however, already being produced by welding, with the aid of the new equipment just commissioned which, in addition to automatic welding equipment, includes facilities for heat treatment, stress removal, sawing to size and ultrasonic testing of plates larger than have hitherto been obtainable in Britain, where rolling mill limitations have restricted plate widths to about 7 ft.

Welding Equipment

Wide plate, available in the non-heat-treatable alloys in thicknesses up to 0.4 in., is made by butt-welding two plates together, so that the final plate can be regarded, for virtually all fabrication work, as normal rolled plate.

The equipment consists essentially of a concrete base 35 ft long, carrying the welding jig. The two pieces of plate to be welded are placed flat, edge-to-edge (with an appropriate welding gap) on the jig, which holds them firmly in place. The overhanging part of one piece of plate is supported on trestles.

The welding is carried out by an automatic Argonaut welding head on a self-propelled carriage at a speed of between 15 and 150 in./min.

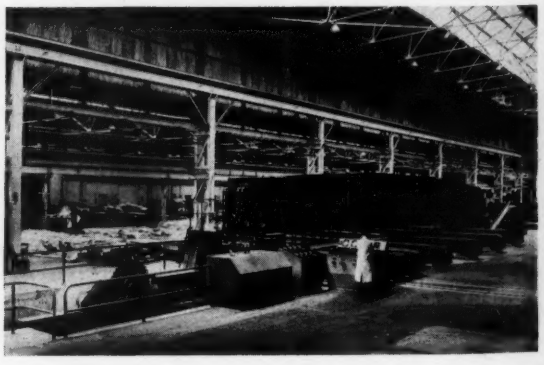
After completion of the weld, which is made in one pass, the top weld bead is removed and the plate lifted off the welding rig by an overhead crane. The plate turn-over mechanism then reverses the plate for removal of the under-bead.

A panel at one end of the base houses the controls for the jig and turn-over mechanism, and the main controls for the welding carriage.

Heat Treatment Furnace

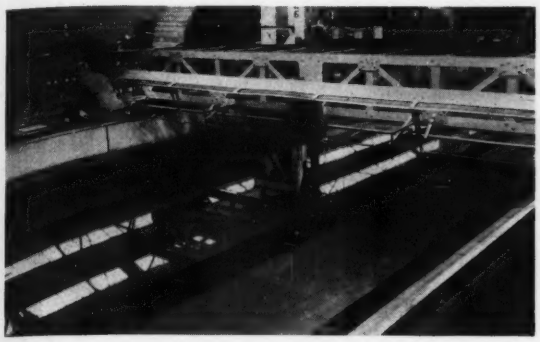
The new furnace for the heat treatment of plate was designed and built by Stordy Engineering Limited to meet the detailed requirements laid down by Northern's general engineering department. It is of the bottom-loading type, with a quench tank immediately below the furnace chamber, and is used for both solution treatment and artificial ageing, as well as annealing of aluminium alloy plate. Its capacity is nearly 20 tons of plate for ageing at temperatures up to 200°C, without quenching; 10 tons for solution-heat-treatment up to 550°C, with a slow quench; and 5 tons for solution-treatment up to 550°C, with a high-speed quench. It can accommodate plates up to 55 ft long, 10 ft wide and 6 in. thick.

The furnace is stainless steel lined, without refractories, and is fully air-circulated, the heater batteries and fans being mounted at each end. The total heater rating is 1,494 kW; each heater battery has three sections (166, 249 and 332 kW) with an independent switching to allow fine temperature control. Four 40 h.p. fans (two at each end of the furnace) are used for circulating air, which is drawn through stainless-steel ducting from the top of the furnace chamber, passing through the fans, then through the heaters, from which it is again ducted to the furnace chamber.



The plate sawing machine, showing saw and carriage at extreme left.

(Right) Control desk and loading conveyors of sawing machine.
(Below) The ultrasonic testing tank.



The furnace door, which is of insulated stainless steel construction, like the furnace itself, slides on electrically driven carriages, and the sealing movement is carried out by hydraulic cylinders, through toggles; a furnace charger runs on rails at each end of the furnace and spans the quenching tank.

The quenching tank is immediately below the furnace and sunk into the floor. It is of concrete and measures 102 ft long, 10½ ft wide and 15 ft deep. Much of this length and width is occupied by circulating pumps and passages, however, and the useful size of the tank for quenching purposes is 60 ft long, 6 ft wide and 15 ft deep. The two axial flow circulating pumps, which have provision for alteration of impeller blade pitch from floor level without withdrawing the pumps, were supplied by W. H. Allen Sons and Company of Bedford.

Plate Stretcher

Locked up stresses in a plate, which can cause distortion during future operations are removed by a controlled stretching operation, which gives a minimum of about 1½% permanent elongation. The new plate stretcher at Rogerstone gives a rated pull of 4,000 tons and can deal with plates up to 50 ft long, up to 10 ft wide, and up to 6 in. thick, with a maximum cross-section of 200 sq. in.

Designed and built by the Loewy Engineering Co., Ltd., it consists of a main compression member on each side of the machine on which are mounted the two main hydraulic cylinders, with rams bearing on side extensions of the main grip-head.

The tail grip-head is adjustable along the compression members, there being nine anchor holes in the compression members, at 4 ft 6 in. pitch.

The grip jaws of both heads are in 10 segments, which do not have to be changed for different plate thicknesses. Each top and bottom pair of segments is mechanically centred, and all are able to move to a small degree relative to each other to accommodate a degree of variation in the thickness of a plate. To give the heavy initial " bite " necessary to hold the plate the jaws are moved by 400-ton hydraulic rams.

Plate Sawing

The new cold saw equipment enables plates up to 55 ft long (future 75 ft) 10 ft wide and 6 in. thick to be cut to size.

The firm location of the plate is assured by the use of 18 pairs of hydraulic jacks carried by the main beam, which is of box section, 68 ft between supports, 6 ft deep at span centre and weighing 20 tons. The saw itself is the result of a considerable amount of development work, and it has been found that carbide-tipped teeth, about 4 in. pitch, with a very deep gullet enables most aluminium alloys to be cut at a very high rate; from 90 in./min for 6-in. plate to 180 ft/min for 3 in. and below, with a peripheral speed of 10,000 ft/min. The saw, driven by a 75-h.p. motor, is housed in a saddle riding on longitudinal bearing surfaces, driven by a 6¼-h.p. feed motor.

At right angles to the beam, there are seven infeed and seven outfeed conveyors for carrying the plate into position. These conveyors are interlocked with the plate clamps. Interlocks are also provided at the control panel for ensuring that the saw feed cannot be applied unless the plate is clamped, and the saw is running.

The machine, which is nearly 140 ft long, was built by Wadkin Ltd., of Leicester; the conveyors were built by the Albert Mann Engineering Co., Ltd., of Basildon.

Ultrasonic Testing

The ultrasonic testing equipment consists of a water tank 54 ft long, 14 ft wide and 3 ft deep, in which the plate is immersed. The scanning unit is mounted on a traversing carriage on a travelling bridge. Scanning can be carried out at speeds up to 50 ft/min, ceasing automatically on the detection of a flaw. A second or " B " scan enables a longitudinal section of the plate to be made, so that a complete picture of the flaw and its position is obtained.

Two views of the plate stretcher.

NIOBIUM—

and Its Alloys

By C. R. TOTTLE, M.Met., A.I.M.,
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Extraction and refining processes have a marked effect on niobium purity and as a result on metal behaviour. Because of high mechanical strength at elevated temperatures and compatibility with uranium and liquid metals niobium or its alloys should find applications in nuclear engineering particularly with fast reactors.

IN the early stages of nuclear reactor development, temperatures attained in the core were kept to a minimum, and hence conventional metals such as aluminium and magnesium, or their alloys, were employed for fuel elements. The advent of higher core temperatures inevitably led to higher thermal stresses, and increased rates of reaction between coolant and canning materials, and between fuel and can. Heat-resisting materials began to receive consideration for fuel elements and other components, commencing with conventional alloys such as austenitic steels and nickel-base materials. Owing to the rapid formation of low melting point eutectics with uranium, the ferrous group metals (Fe, Ni, Cr) cannot be used with safety above 500°C can-fuel interface temperature. The transition metals of higher melting point are more suitable, though not all possess the ideal combination of properties for specific reactor applications.

Niobium is compatible with both solid and liquid uranium up to quite high temperatures (over 1,200°C), and with pure liquid sodium or sodium-potassium alloys up to the boiling point of sodium. The neutron capture cross-section is much higher than that of aluminium for thermal neutrons, but quite acceptable for fast neutron irradiation. The thermal conductivity of the metal is adequate to prevent severe temperature gradients being created through the can wall in the removal of heat energy from the fuel. Thermal expansion of niobium is similar to that of iron.

The mechanical properties of a high melting point metal would be expected to suffer no drastic reduction over the range of temperature involved in a reactor core, and this is so in the case of niobium. The metal is very ductile in its pure state, and not subject to transition to a brittle type of fracture at the temperatures involved in reactor construction and operation. It is resistant to most acid and aqueous media but not particularly resistant to oxidizing gases above 250°C and is, therefore, more suitable for liquid-cooled reactors than for gas-cooled types. Its obvious rôle is that of canning material in fuel elements or structural members operating under high temperature or stress conditions.

Occurrence

Niobium invariably occurs with its sister metal in the periodic system, tantalum, which it closely resembles in all its properties. The principal mineral forms are combined oxides of niobium and/or tantalum with iron and manganese. Composition is variable, and usually either one metal or the other is predominant.

Minerals containing mainly niobium (niobite) occur in Nigeria and the Belgian Congo, with smaller deposits in Bavaria and Finland.[1] Production has varied since 1945, but is steadily rising.

Extraction

The method of extraction of niobium is dependent on the necessity for separation of the tantalum which invariably accompanies it. The use of niobium as an alloying element in steel involves a ferrous alloy, ferro-niobium, which contains tantalum, prepared by reduction of the ore by carbon at high temperature. In this field, no advantage would be gained by separation of the tantalum, and the cost would be exorbitant.

In the nuclear field, however, the fact that tantalum has a much higher capture cross-section for neutrons than niobium, necessitates the separation of most, if not all, of the tantalum. Since the capture cross-section for fast neutrons is less disadvantageous, it may not be essential to remove all the tantalum in this case, but neutron economy may be much improved, even in fast reactors, by the use of pure niobium.

Starting with ore or ferro-niobium, the common first step in extraction processes is to open up by dissolution in a mixture of hydrofluoric and nitric acids; by fusion with an alkali carbonate or oxide or dissolution in a strong aqueous solution of alkali hydroxide. A process utilizing chlorination of the ore or ferro-niobium has also been described.[2]

The second stage, with dissolution processes, involves purification of K_2NbF_7, which is finally reduced by sodium. Alternative processes involve the reduction of Nb_2O_5 or $NbCl_5$. Solvent extraction has been extensively studied in the purification of K_2NbF_7, and also the use of oxalate precipitation to separate tantalum. The chlorination method provides a neat and highly effective separation, but requires further development on the plant scale. A summary of methods studied by the U.K.A.E.A. has been given by Dickson and Dukes.[3]

In all cases except the chlorination method, whether tantalum is separated or not, reduction to metal in the form of powder produces an oxygen-bearing niobium which cannot be processed into shapes at high density without further purification in the metallic state. Hydrogen and nitrogen are also present at this stage, even the chloride reduction powder requiring removal of hydrogen.

A refining stage is, therefore, employed in the preparation of the final material. The metal powder may be compacted in the cold and melted in an arc furnace employing an inert atmosphere, but a very limited refinement with respect to oxygen will result, chiefly due to the local partial pressure of gas in the arc discharge.[4] The electron bombardment melting furnace offers a neat solution to this problem, since a very low pressure can be used in the melting chamber.[4]

By far the simplest method of refinement is the use of the sintering process following cold compaction. In this process, as the temperature is raised, hydrogen is eliminated up to 1,000°C, carbon monoxide is formed above 1,650°C by reaction between any carbon present and some of the oxygen, nitrogen is evolved between 1,900°C and 2,100°C, and, finally, a large proportion of the remaining oxygen is evolved as volatile niobium oxide above 2,000°C.

The evolution of gas must be controlled, particularly above 1,700°C, as otherwise large cavities are created when

the internal pores have no access to the surface. At these very high temperatures, the plastic nature of the metal results in severe blistering. Final removal of oxygen to very low limits is feasible, but the subsequent fabrication of rolled or forged products is unreliable, owing to the initial poor surface and the difficulty of welding up large internal cavities without creation of other metallurgical defects. The two-stage sintering process was, therefore, evolved, in which the initial sintering is used primarily as a refining step to remove the hydrogen, nitrogen, carbon and the bulk of the oxygen present, followed by treatment in hydrogen to embrittle the metal to render it readily crushed to powder for final compacting and sintering.

In the final sinter, the hydrogen used for embrittlement is again removed at low temperatures, and the redistribution of residual oxygen allows steady removal above about 2,000°C without the formation of large internal cavities or surface blisters. It has been shown by Miller[5] that addition of carbon to remove oxygen as carbon monoxide can be used in a commercial process. Details of these processing techniques for the refinement of niobium are available in the proceedings of a symposium held by the Institute of Metals in 1957.[4, 5] Arc melting of sintered niobium may be employed as a finishing stage where large billets are required for fabrication.

Physical Properties

Comparatively little has been published on the properties of niobium metal, and almost nothing on the alloys. Paradoxically, almost all figures published prior to 1953 were, in fact, measurements on alloys (chiefly with oxygen and nitrogen) reported as pure niobium. The recent development of the metal by the U.K.A.E.A. provided some information over a broad field of properties, but attention has been focused, in reporting this work, on the tentative nature of certain results arising from the difficulties in experimental technique.[6] So far as possible, the purity of the metal used has been estimated and included in tables on the data sheet. The author wishes to emphasize that estimates have had to be made where publications did not include the precise information. Nevertheless, it is extremely important to consider any metal whose properties are affected so markedly by atmospheric gases or other impurities, in the light of the method of manufacture or the actual purity of specimens.

Nuclear Properties

Mention has already been made of the neutron capture cross-sections of niobium, which make the metal eminently suitable for fast reactors, provided the tantalum content is not excessive. In the case of thermal reactors the neutron economy is inferior to most metals suitable for low-temperature operation (Al, Mg, Be) but against this must be balanced the superior mechanical properties (discussed below) which would allow reduced section thickness of components to be used, thereby reducing the bulk of metal involved.

Thermal Conductivity

The thermal conductivity of pure niobium is much superior to that of austenitic steels, so that thermal stresses resulting from a severe temperature gradient through the wall of a fuel element can will be less in the case of niobium than for some conventional heat-resisting materials, owing to reduction in the temperature gradient. Furthermore, in common with tantalum, the thermal conductivity of niobium increases with rise in temperature. At 700°C, conduction of heat by niobium is approximately equal to that of molybdenum, which is superior by a factor of 2 at room temperature, but whose conductivity decreases with rise in temperature. (See Table 2 on Data Sheet.)

Thermal Expansion

The values of thermal expansion which have been published show some variation, owing to purity, but suggest that no great difficulties would be expected by the use of niobium in conjunction with other pure metals of comparative heat-resistant properties, although there may be problems of thermal stress concentration when attached to some conventional alloys. (See Table 1.)

Crystal Structure Density

Niobium is a body-centred cubic metal, with no phase changes and a density similar to copper and iron. In applications where the neutron properties are not important, the lower density makes the metal superior to tantalum in reducing the structural mass.

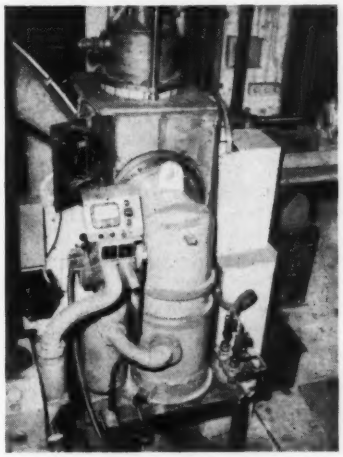

Fig. 1.—Arc melting furnace at Springfields.

Electrical Resistivity

Although this property is not likely to affect applications of niobium to nuclear engineering, it has been measured more frequently than the thermal conductivity to which it is related (by the Wiedemann-Franz-Lorenz law) owing to the smaller specimen size required and the simplicity of the experimental technique. The experimental values are useful therefore in forecasting the thermal conductivity of niobium alloys without the necessity of preparing large specimens of each alloy under investigation. Comparison should be made between Tables 4 and 11. In this connection, the effect of oxygen on thermal conductivity is far greater than that of metals which enter into solid solution with niobium. Table 12 illustrates that a few weight per cent of transition metals in this category cause very little rise in electrical resistivity and, therefore, little decrease in thermal conductivity.

Melting Point

Values for the melting point of niobium have fluctuated over the past 20 years, owing to the impure specimens used, and the failure to preserve an inert atmosphere free from oxygen penetration, during measurement. The most recent work, carried out at the National Physical Laboratory, has been described by Schofield.[7]

Mechanical Properties

A similar warning on the effect of gaseous impurities to that described above for physical properties must be given with respect to mechanical properties. In the latter case,

measurements at high temperatures are particularly difficult, especially where time is a variable, as in creep testing, since the penetration of oxygen into the system is difficult to prevent.

Very few results have been reported on niobium or its alloys. The initial exploratory work carried out by the U.K.A.E.A.[6] is reproduced only to show the trends to be expected. It may be some time before sufficient creep data have been accumulated to enable a fair judgment to be made of the possible applications of niobium alloys. Where compatibility with another material or medium does not cause removal of oxygen, the niobium-oxygen alloys may obviously find a place, due to their extremely high mechanical strength combined with reasonable ductility.

The mechanical properties of pure niobium show no marked peculiarities. The pure metal is extremely ductile, readily fabricated into shapes, and retains its strength up to normal reactor operating temperatures. In comparison with conventional metals and alloys, niobium begins to be of greatest value above 600°C, although the future development of alloys may change this position. A theoretical review of suitable alloy systems has been published by McIntosh,[8] but in considering alloys for nuclear purposes involving mechanical strength, the effect of irradiation may rule out complex systems such as precipitation-hardening alloys, where ageing effects may be completely reversed by neutron bombardment or similar radiation effects. Furthermore, the incorporation of interstitial atoms or compounds to strengthen the metal would require careful checking for nuclear purposes, not only for mechanical properties, but also for stability under irradiation and compatibility with other reactor materials.

Elastic Moduli

Apart from measurements in tension, few results have been published for elastic moduli of niobium. Reynolds[9] has determined certain properties by use of ultrasonic pulse technique. Although the results are generally slightly different from those obtained by direct mechanical testing, agreement for niobium seems reasonable. Values obtained for Young's modulus on niobium appear to vary not only with oxygen content but also with the degree of working to which the sample has been subjected. This may indeed be another reflection of oxygen content, since pure niobium does not work-harden appreciably, and a process of ageing may be involved. (Table 5.)

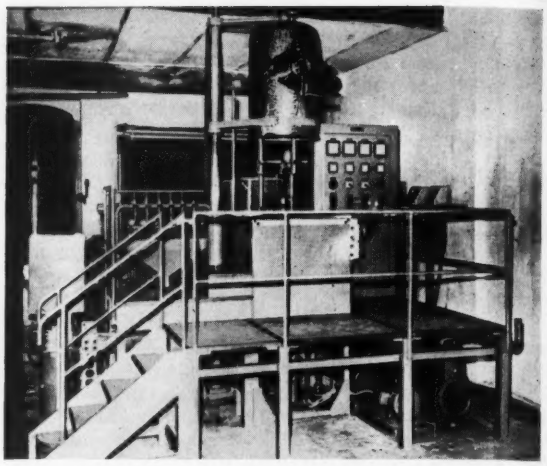

Fig. 2.—Vacuum sintering unit at Springfields.

Tensile Properties

The tensile strength of niobium falls slowly with rise in temperature.

Heavily worked and annealed material possesses greater strength than completely annealed material which has been worked just sufficiently to achieve theoretical density. In

Le Niobium et ses Alliages

Le Niobium présente un intérêt pour les applications nucléaires par suite de sa résistance mécanique aux températures des noyaux de réacteurs, et sa compatibilité avec l'uranium et avec un grand nombre de liquides, y compris les métaux liquides. Les propriétés physiques sont raisonnables, la conductivité thermique étant meilleure que celle de beaucoup d'alliages résistant à la chaleur conventionnels, mais la capture des neutrons, tout en étant bonne pour les réacteurs à fission rapide, porterait atteinte à l'économie des neutrons dans les réacteurs thermiques. Le métal est très ductile à l'état pur, se travaille facilement à froid, et peut être soudé avec des précautions spéciales pour conserver une atmosphère inerte. L'effet des gaz atmosphériques sur ses propriétés, particulièrement la résistance mécanique et la ductilité, est discuté dans cet article, et la feuille de données comprend des preuves de l'effet de l'oxygène en particulier.

L'extraction et le raffinage du métal sont examinés assez détaillément, en vue de l'effet sur le comportement ultérieur d'après la pureté. On en conclut que le niobium ou ses alliages trouveraient des applications dans les réacteurs rapides refroidis par liquide en particulier.

Niob und seine Legierungen

Niob ist in der Atomkraft-Verwertung von Interesse wegen seiner mechanischen Festigkeit bei den im Reaktor Kern vorkommenden Temperaturen und wegen der Möglichkeit der Verwendbarkeit zusammen mit Uran und mit vielen Flüssigkeiten mit Einschluss von flüssigen Metallen. Seine physikalischen Eigenschaften sind zweckmässig, die Wärmeleitfähigkeit ist besser als bei vielen konventionellen wärmebeständigen Legierungen, jedoch würde der Neutronen Einfang, wenn auch gut für schnelle Spaltungs Reaktoren, die Neutronen-Wirtschaftlichkeit in thermischen Reaktoren beeinflussen. Das Metall ist sehr bildsam, wenn rein, leicht zu bearbeiten in kaltem Zustand, und kann unter besonderen Vorsichtsmassregeln geschweisst werden, wenn es nämlich in einer neutralen Atmosphäre geschieht. Die Wirkung atmosphärischer Gase auf seine Eigenschaften, insbesondere auf die mechanische Festigkeit mit Bildsamkeit wird besprochen; das Blatt mit der Zusammenstellung der Daten bringt spezielle Zahlen über die Wirkung des Sauerstoffs.

Die Extraktion und Raffinierung des Metalls wird in ziemlicher Ausführlichkeit behandelt im Hinblick auf die Wirkung, die dies auf das spätere Verhalten hat je nach dem Reinheitsgrad. Es wird der Schluss gezogen, dass Niob oder seine Legierungen insbesondere Anwendung finden könnten in Flüssigkeit-gekühlten schnellen Reaktoren.

Niobio y sus Aleaciones

El niobio es de interés para aplicaciones nucleares debido a su resistencia mecánica a las temperaturas de los núcleos de reactores, y su compatibilidad con el uranio y con muchos líquidos, incluyendo los metales líquidos. Sus propiedades físicas son razonables, siendo su conductividad térmica major que la de muchas aleaciones resistentes al calor, pero la captura neutrónica, mientras que es buena para reactores de fisión rápida, afectaría la economía neutrónica en los reactores térmicos. El metal es muy ductil cuando está puro, es fácilmente fabricado en frío, y puede ser soldado con precauciones especiales para preservar una atmósfera inerte. El efecto de los gases atmosféricos sobre propiedades, particularmente la resistencia mecánica y la ductilidad, es discutido, y la hoja de datos incluye evidencia sobre el efecto del oxígeno particularmente.

Se discute detalladamente la extracción y el refinamiento del metal, en vista del efecto sobre comportamiento subsecuente, según la pureza. Se llega a la conclusión que el niobio y sus aleaciones encontrarían aplicación particularmente en reactores rápidos enfriados con líquidos.

annealed material the values of U.T.S. and limit of proportionality show approximately the same proportionate changes with rise in temperature, whatever the initial state of the material (Table 6) such that limit of proportionality is reduced by a factor of about 2 at 500°C compared with room temperature values.

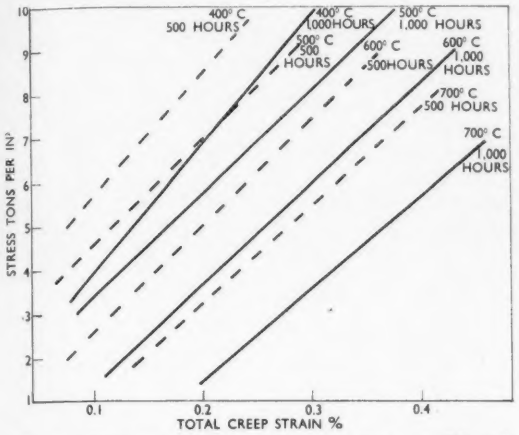
400° C 500 HOURS
400° C 1,000 HOURS
500° C 500 HOURS
500° C 1,000 HOURS
600° C 500 HOURS
600° C 1,000 HOURS
700° C 500 HOURS
700° C 1,000 HOURS
STRESS TONS PER IN²
TOTAL CREEP STRAIN %

Fig. 3.—Stress to produce total creep strain in 500 and 1,000 hours in niobium over range of temperatures 400° to 700°C.

That ductility is much more sensitive to oxygen content than to rise in temperature is evident by comparison between Tables 6 and 11. These results show that 0.3% by weight of oxygen reduces the ductility at room temperature by the same order as a rise in temperature of 500°C on material containing less than 0.03 weight per cent of oxygen.

Recent evidence[20] suggests that niobium may be subject to strain ageing phenomena. Specimens cut from cold-drawn tubes show lower ductility at 500°C than at 300°C or less. The ductility is restored, however, on lowering the temperature. Table 7 shows recent results obtained on samples of heavily cold-rolled material before and after annealing at 1,100°C. A sudden increase in ductility occurred in the annealed specimens tested at 600°C, accompanied by a drop in limit of proportionality, which may be an indication of over-ageing.

Alloying elements which form solid solutions with niobium reduce the ductility, whilst increasing the room temperature tensile strength to a lesser extent. Hardness is also increased by the addition of these elements, so that fabrication is rendered more difficult. (Table 12.)

Creep

Niobium undergoes rapid deformation at high temperature when a load is applied, but the primary stage of creep soon changes to a long transient stage with low rates of deformation.

No reliable values have been recorded for stress to rupture at elevated temperatures, probably because of the difficulty in conducting long-time tests without marked increase in the oxygen content. In an oxygen-free environment, niobium may show much less tendency to approach difficulty in conducting long-time tests without marked or alloys of lower melting point. Certainly the existing creep data, scanty though they may be, indicate the possibility. (Table 8.)

An attempt has been made to present the available creep data to show the stress required to produce a given total creep strain in 500 and 1,000 hours at temperatures from 400°C to 700°C (Fig. 3). The data should be treated with caution, as the evidence suggests that the secondary creep of niobium is sensitive to any effects which modify the primary stage. Nevertheless, the straight line relationship shown is based on a minimum of three points with supporting evidence from tests not shown in Table 8.

Compatibility

Gases. Reference has already been made to the rapid reaction between niobium and atmospheric gases at high temperatures. At room temperature, attack is very slow, exposure to an industrial atmosphere producing slight tarnishing.[8] Niobium exposed to air at 200°C to 300°C forms coloured films of oxide on the surface, without excessive diffusion of oxygen into the interior. At these temperatures, however, nitrogen does diffuse and slight embrittlement results.[10] Hydrogen causes embrittlement following absorption at 400°C. At 500°C, exposure to air, or CO_2 at 8 atmospheres pressure, gives rise to a loose friable scale following a linear rate law. McIntosh[8] has discussed the possibilities of improving the oxidation resistance of niobium by alloying, and suggests that zirconium may be effective in this connection.

There appears to be little evidence to support the application of niobium in any oxidizing atmosphere above 400°C to 500°C, even with alloying elements added, so that in gas-cooled reactors application may be confined to cooler portions of the structure. (Table 14.)

Aqueous Solutions. Niobium possesses excellent resistance to attack by nitric acid at all concentrations, and to dilute hydrochloric acid. In concentrated hydrochloric acid, resistance falls above 80°C, and in concentrated sulphuric acid, above 40°C. Nevertheless, niobium is superior to all other metals, in the latter environment, except tantalum and platinum. (McIntosh,[8] Table 9.)

In other aqueous media, attack is normally slight until temperatures reach 80°C (Table 10). The disadvantage of attack by aqueous media is the accompanying embrittlement by diffusion of hydrogen. The presence of fluoride ion leads to rapid attack of niobium.

There is little or no evidence available on the effect of alloying elements on corrosion, but presumably an element leading to oxidation-resistance should increase resistance to oxidizing acid attack.

Niobium may, therefore, find application in chemical plant for processing nuclear fuels or reactor materials which are worthy of recovery. Although probably slightly inferior to tantalum in this respect, the lower density may prove advantageous. The embrittlement by hydrogen might be compensated by use of backing materials, unaffected by hydrogen diffusion but with inferior corrosion resistance, wherever stress may be an important factor.

Liquid Metals. Niobium shows little tendency to form solutions with metals of low melting point at temperatures up to 600°C. Thus, the solubility of niobium in lithium, mercury, tin, lead, bismuth, sodium and sodium-potassium alloys is reported to be extremely small.[8] Few results on the corrosion of niobium by these metals have been published, but it is emphasized that the presence of oxygen as an impurity in the liquid metal increases the corrosion rate markedly at temperatures above 400°C. Purification of the liquid metal by cold trapping of the oxide (i.e., precipitation of the oxide at a temperature just above the melting point of the metal, where its solubility is a minimum) is a possible solution to this problem.

No assessment of the effect of alloying elements in niobium on compatibility with liquid metals has so far been reported.

Solids. Few results have been published of compatibility

between niobium and solid materials of interest in nuclear applications (e.g. fuels). Nevertheless, the interest in niobium and qualitative statements regarding its suitability for such applications[11, 8] indicate that niobium does not

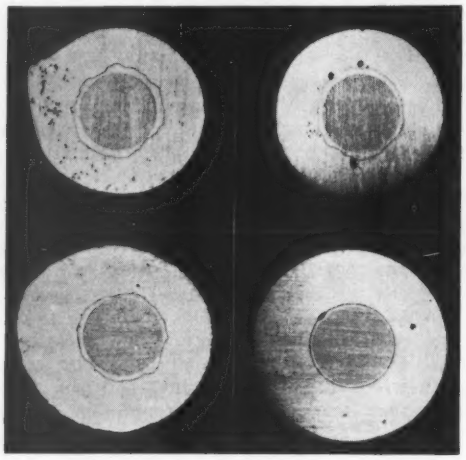

Fig. 4.—Reaction between uranium and niobium. Top left—1 h at 1,250°C, right—8 h at 1,200°C. Bottom left—16 h at 1,150°C, right—6 weeks at 900°C.

react with uranium until high temperatures are reached. In contact with graphite, the carbide is not likely to be formed at normal reactor temperatures, judging by the methods available for producing the carbide.

The use of niobium in the Dounreay experimental fast reactor[12] suggests that it satisfies the requirements of a uranium-fuelled NaK-cooled fast reactor.

Fabrication

Shaping. The niobium metal produced by sintering in the first stage is of low density. The second sintering stage raises the density[4] from 7.0 to 8.3 g/cm^3. The niobium is then extremely ductile, and can be cold-rolled directly from, say, ½ in. bar to 0.005 in. sheet. The density is then up to the theoretical value. No stress-relieving is necessary in this process, but the introduction of more complex shaping (e.g. cupping) requires intermediate heat-treatment operations to relieve the complex stresses set up. (Table 13.)

Hot-forming operations cannot be used in view of the attack by atmospheric gases, and the temperatures required for stress-relief (1,000°C to 1,250°C) involve the use of an inert atmosphere or vacuum.

Sheet rolling requires no special techniques. Tube production by cupping and drawing involves care in adjusting the thickness/diameter ratio of blanks for cupping (1 : 50) and the percentage reduction applied (50% average) at each operation. In draw-bench operations, single reductions of area up to 35%, with total reductions of 60-80%, are possible, between annealing treatments.[4] Lubrication is necessary in drawing, to prevent galling. Aluminium bronze has been found most successful for dies and punches used in shaping niobium cups and tubes.

Rod and wire are produced in the same manner as sheet, except that rod rolling or swaging replaces the flat roll operation. Wire-drawing requires care in lubrication, as for tube-drawing.

There is little information on extrusion of niobium, but no difficulties are anticipated other than the obvious requirement for protection from atmospheric attack. Spinning from sheet should offer little difficulty.

As would be expected, niobium alloys developed for creep-resistance have been found more difficult to fabricate.

Joining. The obvious difficulties in joining niobium—high melting point and atmospheric attack—have already been emphasized. Spot welding has been found effective, with sound ductile joints produced. Argon-arc welding necessitates complete blanketing of the metal until the temperature has fallen to 200°C. A container fitted with special seals or completely enveloping the workpiece is, therefore, essential, with a supply of argon under pressure. Evacuation of the container before filling with argon speeds up the sequence of purging atmospheric gases. Both a.c. and d.c. circuits have been used, and Williams[4] quotes the tensile strength of the weld as approximately 85% that of the parent metal.

Machining. Niobium can be machined by normal techniques, but the ductile nature of the pure metal requires adjustment of rake angles to prevent "scuffing" due to plastic flow of the chip against the tool point. Normal soluble cutting oils have been used as lubricants and carbon tetrachloride has been reported as suitable for this purpose.[15, 24]

Reactor Conditions

There is little published evidence on the behaviour of niobium or its alloys under irradiation. The fact that the metal undergoes no phase change implies that thermal cycling effects will be negligible. The results of creep tests do not suggest any unusual thermal effects arising from temperature, or stress-dependent metallurgical changes.

The pick-up of oxygen, nitrogen or hydrogen, however, would immediately affect the mechanical and physical properties, and would be temperature-dependent. Large quantities (over 0.5% by weight of oxygen) would involve secondary metallurgical changes with the precipitation of new phases. Since this would be regarded as an alloy, further evidence on changes under reactor conditions must await the development of alloys.

General

Niobium has much to offer in the field of liquid-cooled reactors not involving oxidizing conditions, particularly where high temperatures are involved. The extraction process is tedious, but manufacture is comparatively free from severe troubles arising from peculiar properties. The production and fabrication of the metal, and its alloys, will always be expensive, owing to the necessity for protection from atmospheric attack during sintering, melting, heat-treatment and joining. Nevertheless, future development should simplify techniques, and perhaps, improve the relevant properties in such a way that the cost is justified by the behaviour in service.

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Nuclear Engineering

DATA SHEET

No. 7. Niobium

PROPERTIES OF NIOBIUM

Symbol	Nb
Atomic Number	41
Atomic Weight	92.91
Atomic Volume	10.8 cm³/g, atom.
Crystal Structure	Body centred cubic
Unit cell dimensions at 20°C	3.3004 ± 0.003 Å
Density at 20°C	8.66 g/cm
Thermal Expansion	Table 1
Thermal Conductivity	Table 2
Specific Heat	$C_p = 5.66 + 0.96 \times 10^{-3}T$ cal/°C, mole. (16) (T=°K)
Neutron Cross-section	Table 3
Electrical Resistivity	Table 4
Work Function	4.01 eV (13)
Emissivity	0.37 at λ = 6500 Å
Melting Point	2468° ± 10°C (7)
Elastic Moduli	Table 5
Hardness at 20°C	76 V.P.N. at 99.95% purity
Hardness at elevated temperatures	Table 7
Tensile strength and ductility	Tables 6 and 7
Creep Properties	Table 8
Compatibility	Tables 9, 10 and 14

TABLE 1
Thermal Expansion

Temperature °C	100	200	300	400	500	600	700	800	900	1,000	Ref.	Purity %
Linear co-eff. between 18°C and temperature °C⁻¹×10⁻⁶	7.20	7.38	7.56	—	—	—	—	—	—	—	16	98.50
	—	—	7.31	7.39	7.47	7.56	7.64	7.72	7.80	7.88	6	99.90
	7.10	7.21	7.32	7.42	7.53	7.64	7.76	7.85	7.95	—	20	99.92
Instantaneous linear co-eff. °C⁻¹×10⁻⁶	7.10	—	—	—	—	—	—	—	—	—	18	99.0
	—	—	7.38	7.54	7.61	7.87	8.03	8.20	8.37	8.52	6	99.90
	7.19	7.40	7.62	7.83	8.04	8.25	8.46	8.63	8.89	—	20	99.92

TABLE 2
Thermal Conductivity

Temperature °C	0	100	200	300	400	500	600	Ref.	Purity %
Thermal conductivity calcm⁻¹ sec⁻¹ °C⁻¹	0.125	0.130	0.135	0.140	0.145	0.151	0.156	6	99.90
	—	—	0.131	0.134	0.137	0.140	0.143	20	99.92

TABLE 3
Neutron Cross-section

Reaction cross-section—barns		Scattering cross-section—barns			Neutron Energy	Ref.
σ(abs.)	σ(act.)	σ(coh), sign	$\sigma(i\alpha)\left(\frac{A+1}{A}\right)^2$	$\overline{\sigma}(s)$		
1.1±0.1	1.0±0.5	6.6±2(+)	6.0±0.3	5±1	Thermal	14
0.08	—	—	—	—	Fast	22

TABLE 4
Electrical Resistivity

Temperature °C	0	100	200	300	400
Electrical Resistivity microhm cm	—	14.1	—	—	—
	16.0	—	—	—	—
	13.1	—	—	—	—
	15.22	19.18	23.13	27.09	31.04

TABLE 5
Elastic Moduli

Property	20	Temperature °C			
		100	200	300	400
Young's Modulus E lb/in.²	15.1	—	—	—	—
	19.0 (40°C)	—	—	—	—
	12.4	—	10.9	8.0	7.5
	15.2	—	14.7	14.5	14.6
	15.9	—	—	—	14.1
Shear Modulus N lb/in.²	5.44				
Bulk Modulus K	26±1 (calculated)				
Poisson's ratio	0.3				
	0.38				

Test Temperature °C	Condition of metal
40	Annealed ..
260	Annealed ..
540	Annealed ..
20	Annealed ..
20	Heavily cold rolled ..
20	Forged, cold rolled to
200	bar annealed 1300°C
300	for 1 hour in vacuo
400	
500	
550	
20	Cold rolled to 170
200	V.H.N. then anneal-
300	ed at 1100°C for ½ h
400	in vacuo. Tested in
500	direction of rolling

Effect of Annealing o

Test temperature °C	Condition of metal	p
20	Sheet annealed at	
200	¼-in. thickness cold-	
300	rolled to 0.004 in.	
400	Tested in direction	
500	of rolling	
600		
20	As above then an-	
200	nealed ½ hr at	
300	1,100°C in vacuum	
400	better than 10^{-5}	
500	mm Hg.	
600		

TABLE 4
ectrical Resistivity

100	200	300	400	500	600	Ref.	Purity %
14.1	—	—	—	—	—	16	98.6
—	—	—	—	34.5	—	17	unknown
—	—	—	—	—	—	18	99.0
19.18	23.13	27.09	31.04	35.0	38.96	6	99.95

TABLE 5
Elastic Moduli

Temperature °C						Ref.	Purity %
100	200	300	400	500	550		
—	—	—	—	—	—	9	99.0
—	—	—	—	—	—	19	99.9
—	10.9	8.0	7.5	6.4	4.7	6	99.95
—	14.7	14.5	14.6	14.2	—	12	99.95
—	—	—	14.1	—	—	20	99.95
						9	99.0
						9	99.9
						19	99.9
						9	99.0

TABLE 6
Tensile Properties

ture	Condition of metal	Limit of proportionality tons/in.²	U.T.S. tons/in.²	Elongation % on 4.√area	Ref.	Purity %
	Annealed		19.1		22	99.0
	Annealed		17.4			
	Annealed		14.2			
	Annealed		22.3	30	21	99.90
	Heavily cold rolled ..		44.6	1		
	Forged, cold rolled to bar annealed 1300°C for 1 hour in vacuo	10.8	17.6	49	6	99.95
		6.5	15.0	48		
		6.3	15.5	38		
		6.5	14.8	28		
		6.8	15.9	35		
		4.7	14.4	24		
	Cold rolled to 170 V.H.N. then annealed at 1100°C for ½ h in vacuo. Tested in direction of rolling	16.8	22.4	29.6	12	99.92
		10.0	17.6	30.9		
		10.2	19.6	31.2		
		8.6	18.4	22.9		
		8.4	19.0	22.2 (% on 1½ in.)		

TABLE 7
Effect of Annealing on Mechanical Properties of Cold-rolled Sheet

Condition of metal	Limit of proportionality tons/in.²	U.T.S. tons/in.²	Elongation on 1½ in.	Vickers hardness number	Ref.	Purity %
Sheet annealed at ⅛-in. thickness cold-rolled to 0.004 in. Tested in direction of rolling	35.0	37.5	4.7	156	20	99.92
	27.2	31.2	Broke outside gauge length	149		
	32.6	37.8		169		
	33.0	34.6		154		
	31.9	35.4	2.4	162		
	33.6	34.6	3.2	145		
As above then annealed ½ hr at 1,100°C in vacuum better than 10^{-5} mm Hg.	18.6	22.1	19.2	94	20	99.92
	15.5	23.9	14.2	115		
	13.1	20.0	13.2	94		
	14.3	21.9	13.3	107		
	12.6	22.0	9.6	96		
	8.0	20.8	17.5	100		

TABLE 8
Creep Properties

Material	Temperature °C	Stress tons/in.²	Time required for specified creep strain-hours						Minimum creep rate in./in./h $\times 10^{-6}$
			0.05%	0.1%	0.2%	0.3%	0.5%	1.0%	
Annealed 1,100°C ..	400	4	160	800	—	—	—	—	0.44
Annealed 1,100°C ..		6	115	445	2,020	—	—	—	0.58
Annealed 1,100°C ..		8	20	120	645	—	—	—	0.86
Annealed 1,150°C ..		8	22	152	608	—	—	—	0.87
Annealed 1,100°C ..	500	4	—	—	—	—	—	—	0.52
Annealed 1,150°C ..		8	90	195	—	—	—	—	0.53
Annealed 1,150°C ..		8	85	140	390	—	—	—	0.24
Annealed 1,150°C ..		10	22	59	123	—	—	—	5.3
As rolled		10	—	10	18	35	400	1,295 (0.6%)	—
Annealed 1,100°C ..	600	4	27	110	1,470	—	—	—	1.6
Swaged bar		4	50	160	860	2,130	—	—	—
Annealed 1,300°C ..		5	5	15	35	—	165	980	2.3
As rolled		6	40	130	345	1,160	—	—	—
Annealed 1,100°C ..		8	15	60	—	—	—	—	0.2
Swaged bar	700	1	40	290	1,560	—	—	—	
Swaged bar		2	80	205	550	1,495	—	—	
Swaged bar		3	120	220	540	1,115	—	—	
Swaged bar	1,000	2.8	—	—	—	—	—	24	—
Swaged bar		5.0	24	—	—	—	—	—	—

TABLE 9
Resistance to Mineral Acids

Acid and concentration	Penetration—mm/year			
	20°C	40°C	60°C	
Conc. HCl ..	<0.01	0.01—0.1	0.01—0.1	0.
*Dil. HCl ..	<0.01	<0.01	<0.01	
Conc. HNO_3 ..	<0.01	<0.01	<0.01	
*Dil. HNO_3 ..	<0.01	<0.01	<0.01	
Conc. H_2SO_4 ..	0.1—1.0	0.1—1.0	0.1—1.0	
*Dil. H_2SO_4 ..	<0.01	<0.01	<0.01	0.

* Dilute here refers to 10% by volume of the concentrat

TABLE 10
Resistance to Aqueous Solutions

Material	Concentration % by weight	Penetration mm/	
		21°C	10
Phosphoric acid ..	85	nil	0.01
Tartaric acid	20	nil	
Oxalic acid	10	approx. 0.01	
Ammonia	—	nil	
Sodium Carbonate ..	20	—	0.0
Caustic Soda ..	5	0.01—0.1	0.1
Caustic Potash ..	5	0.1—1.0	
Hydrogen Peroxide ..	30	<0.01	

TABLE 11
Electrical Resistivity and Tensile Properties of Niobium- at Room Temperature

Oxygen content weight%	Electrical resistivity microhm, cm	Mean Vickers hardness number	Limit of proportionality tons/in.²	U.T.S. tons/in.²
0.03	16.25	87	12.6	18.35
0.161	18.79	194	27.3	34.1
0.208	22.11	208	30.9	40.7
0.279	24.12	248	34.6	44.3
0.315	25.67	278	43.6	60.9
0.375	26.18	314	47.4	61.0
0.410	26.59	331	48.1	58.6
0.565	30.60	390	Specimen cracked before	

%	Minimum creep rate in./in./h $\times 10^{-6}$	Duration of test hours	Total creep strain %	Ref.	Purity %
	0.44	1,819	0.145	20	99.92
	0.58	2,700	0.224	20	99.92
	0.86	1,603	0.286	20	99.92
	0.87	1,536	0.289	20	99.92
	0.52	362	0.037	20	99.92
	0.53	725	0.171	20	99.92
	0.24	1,870	0.270	20	99.92
	5.3	338	0.345	20	99.92
95	—	—	—	6	99.95
%)					
	1.6	1,325	0.34	20	99.92
	—	5,519	0.306	6	99.95
00	2.3	1,359	1.08	6	99.95
	—	—	—	6	99.95
	0.2	2,117	0.198	20	99.92
		2,314	0.22	6	99.95
		5,008	0.36	6	99.95
		3,335	0.40	6	99.95
24	—	—	—	23	99.95
	—	—	—	23	99.95

Acids

—mm/year		Ref.
60°C	80°C	
0.01—0.1	0.1—1.0	8
<0.01	<0.01	
<0.01	<0.01	
<0.01	<0.01	
0.1—1.0	>1.0	
<0.01	0.01—0.1	

f the concentrated acid.

olutions

enetration mm/year		Ref.
°C	100°C	
il	0.01—0.1	10
il	—	
x. 0.01	—	
il	—	
—	0.01—0.1	
—0.1	0.1—1.0	
—1.0	>1.0	
0.01	—	

s of Niobium-Oxygen Alloys
ture

lity	U.T.S. tons/in.²	Elongation on 1½ in. %	Ref.
	18.35	29.3	6
	34.1	16.9	
	40.7	17.7	
	44.3	20.7	
	60.9	20.5	
	61.0	10.4	
	58.6	9.8	

cracked before loading.

TABLE 12

Effect of Alloying Elements on Mechanical Properties and Electrical Resistivity of Niobium at 20° and 500°C

Base material purity	Alloy composition	Electrical resistivity at 20°C microhm cm	Vickers hardness number		Limit of proportionality tons/in.²		U.T.S. tons/in.²		Elongation % on 1 in.		Ref.
			Sintered and pressed	Rolled to 0.02 in. thickness	20°C	500°C	20°C	500°C	20°C	500°C	
99.95% Nb	—	16.25	87	—	12.6	—	18.4	—	29.3	—	6
99.95% Nb	5% Mo	16.97	150	—	24.3	—	27.0	—	16.8	—	6
99.95% Nb	6½% Mo	—	150	—	—	—	37.6	—	15.0	—	6
99.95% Nb	7½% Mo	—	159	—	30.9	—	40.2	—	13.3	—	6
99.95% Nb	10% Mo	17.6	167	—	24.2	—	31.0	—	8.5	—	6
99.95% Nb	5% W	17.2	111	—	13.3	—	19.9	—	8.9	—	6
99.95% Nb	7½% W	—	113	—	25.4	—	33.7	—	10.4	—	6
99.95% Nb	10% W	21.1	191	—	25.8	—	29.7	—	9.9	—	6
*99.95% Nb	1% Zr	15.82	75	—	10.7	—	18.8	—	18.2	—	6
*99.95% Nb	2% Zr	17.53	94	—	14.1	—	20.0	—	11.5	—	6
99.95% Nb	10% Zr	—	111	—	19.7	—	26.8	—	10.7	—	6
†99.95% Nb	2% V	—	123	—	18.9	—	24.9	—	11.2	—	6
99.95% Nb	2% Ti	18.86	100	—	14.1	—	18.0	—	14.6	—	6
99.95% Nb	5% Ti	—	147	—	21.7	—	24.7	—	15.3	—	6
99.95% Nb	1% Pt	—	94	—	14.05	—	19.4	—	13.2	—	6
‡99.98% Nb	—	14.8	46	93	—	—	13.4	—	32.6	—	20
99.98% Nb	7.6% Mo	16.2	101	211	22.6	7.6	27.5	17.3	21.9	9.7	20
99.98% Nb	9.4% Mo	16.75	113	220	24.0	9.0	30.7	21.1	24.0	6.0	20
99.98% Nb	1.6% V	16.0	63	166	18.5	8.2	28.6	16.3	19.0	12.8	20
§99.98% Nb	3.1% V	17.4	81	193	20.7	11.8	26.4	21.7	19.1	9.6	20
99.98% Nb	4.6% V	18.6	88	209	24.5	15.9	30.6	25.4	21.1	5.9	20
99.98% Nb	2% Al	19.4	54	133	12.2	7.8	17.3	16.7	28.0	12.2	20
			As cast								
99.98% Nb	4% Ti		116	190							20
99.98% Nb	6% Ti		129	200							20
99.98% Nb	8% Ti		133	212							20
99.98% Nb	10% Ti		146	204							20
99.98% Nb	5% Ta		102	159							20
99.98% Nb	10% Ta		105	176							20
99.98% Nb	15% Ta		106	177							20
99.98% Nb	2% Zr		136	—							20
99.98% Nb	4% Zr		176	—							20
99.98% Nb	6% Zr		210	—							20

* Impure Zr. † Impure V ‡ Specially purified niobium used. § Fracture outside gauge length.

TABLE 13

Effect of Cold Rolling on Hardness of Niobium

Reduction in area %	Vickers hardness number		Ref.	Purity %
	Perpendicular to rolling direction	Parallel to rolling direction		
*0	84	84	20	99.95
10	104	104		
20	118.5	113.5		
30	128.5	119		
40	136.5	123		
50	142.5	128		
60	148	132.5		

* Original material fully annealed.
No edge cracking observed in any specimen.

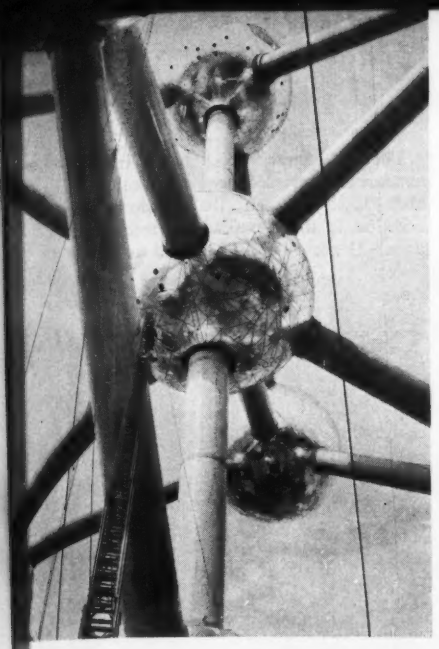
TABLE 14

Atmospheric Oxidation of Niobium Alloys at 450°C for 25 hours

Alloy	Vickers hardness number			Penetration mm/year	Ref.
	Initial	After test	% Increase		
99.92% Nb ..	96	149	55	0.016	20
Nb–2% Al ..	90	213	136	0.102	
Nb–6% V ..	160	225	40	0.044	
Nb–8% Mo ..	160	309	93	0.026	

BRUSSELS—

First Impressions



Part of the Atomium during construction.

ALTHOUGH the Brussels Exhibition cannot by any means be considered a trade fair, and has a popular appeal, there is little doubt that from the nuclear point of view, both the U.K. and the U.S.A. have made a really serious effort to publicize their own achievements. As might be expected the PWR type is emphasized both in the U.S. pavilion and in the Westinghouse exhibit in the Atomium, in which there is a model of the pressure vessel and core of the Yankee project, 26 ft high, into which it is possible to walk. The model exhibited in the U.S. pavilion is considerably smaller. A number of other types of reactor are shown in model form, including an animated model of a graphite pile for producing isotopes.

Other U.S. exhibits of interest include the latest design of master-slave gear developed by the Argonne Laboratories. Electronically coupled, this gear enables true remote control to be obtained, remote three-dimensional television being used for long-distance operation.

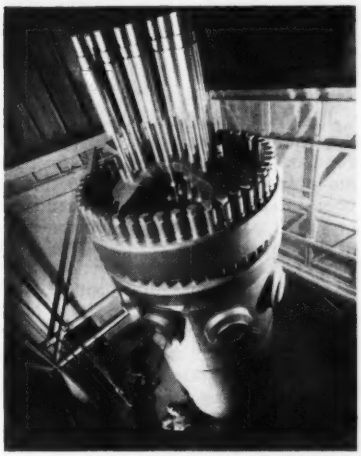
U.S.S.R.

The Russian exhibits include "Perspex" models of three nuclear power stations; the original 5 MW unit (*Nuclear Engineering*, November, 1956, p. 331), the 420 MW pressurized water design (*Nuclear Engineering*, October, 1957, p. 431) and a fast reactor unit said to have an electrical output of 50 MW, which is still in the design stage.

U.K.A.E.A.

The Atomic Energy Authority is represented in the British Government pavilion by means of a one-third full-size model of ZETA, and an exceedingly effective diorama of the Dounreay sphere. Dounreay is again featured on the Authority's own stand in the British Industries pavilion. In this case the model sphere has a diameter of 17 ft and the inner workings are clearly shown. A model of the high-temperature gas-cooled reactor being built at Winfrith Heath is being shown for the first time. There is also an animated diagram of the homogeneous aqueous reactor. Models of the power stations under construction for Berkeley, Bradwell, Hunterston and Hinkley Point are also shown on this stand.

The A.E.A. is also represented in the International Hall of Science in three of the four sections atom-molecule-crystal-living cell, including a model of Sir John Cockroft's laboratory where he and Prof. Walton first split the atom with artificially accelerated particles. A model of the 7 GeV proton accelerator being built at Harwell for the National Institute for Nuclear Research is shown in the high-energy physics section.

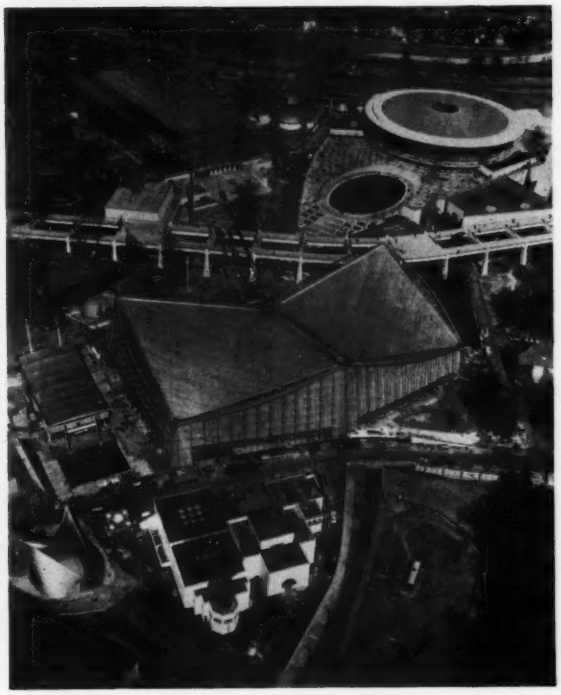


British Industry

The British Industries pavilion was noteworthy not only for being practically the only part of the exhibition actually functioning in time, but for the variety and extent of its display. In addition to the co-operative effort with its central theme "Power for Progress" organized by the British Electrical and Allied Manufacturers' Association, individual companies and consortia had their own exhibits. Three Chambers of Energy, as they are termed, in the form of cylindrical enclosures, contain exhibits relating to thermal energy, nuclear energy and water. This collective exhibit covers some 5,000 sq. ft.

A portion of the Babcock and Wilcox stand is given over to the activities of the English Electric-Babcock and Wilcox-Taylor Woodrow, Ltd. group, the theme being the Hinkley Point power station. The theme of the Babcock stand is "Steam Power in the Service of Mankind," and is largely devoted to the use of conventional fuels. A mural by Anna

(Above) The Westinghouse model of the Yankee reactor during construction.



(Right) Helicopter view of part of the International Section. The circular pavilion is the U.S., the U.S.S.R. is to the left of it. In the centre of the picture is France.

The Pavilion of British Industry.

Zinkeisen and a set piece represent the benefits of steam power to mankind in modern times. Models displayed on the stand include one of the Calder type heat exchangers, and a pressure vessel 35 ft by 12 ft 5 in. diameter and 5-6½ in. thick for a PWR reactor to operate at 1,200 p.s.i. A further model represents the hull of a large tanker showing the possible layout of gas-cooled graphite moderated reactor plant for propulsion, based on actual project studies.

To say that the Nuclear Power Plant Co.'s stand contains a model is a rather inadequate way of putting it. It would, in fact, be more correct to say that the model contains the stand. Based on the Bradwell station, this model must be at least 1 in. to the foot; in fact, the stand office is inside one of the reactor houses. The other reactor is sectioned, and the reactor and heat exchanger portions are animated.

The external architecture of the pavilion strikes a note of dignified simplicity. Designed by Edward D. Mills and Partners and built by Richard Costain, Ltd., in association with the Belgian company of Blaton-Aubert, it contains over 33,000 sq. ft of plate glass supplied by Pilkington Bros.

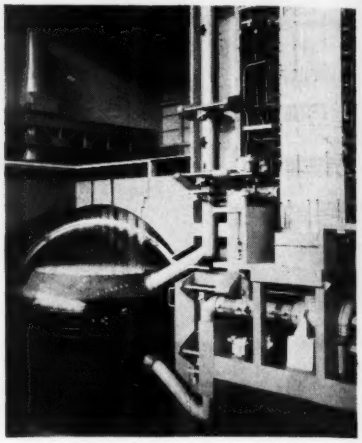
The Atomium

The "Atomium," the central theme of the exhibition, is really based on a conventional representation of a metallic molecule magnified some 165 billion times. Representing a body-centred cubic crystal, it consists of nine spheres, eight at the corners of the cube, and the ninth located centrally, tied together by tubes and resting on one corner sphere, with the diagonal vertical, the three lower spheres being supported by bipod structures. The overall height is 334.6 ft and the diameter of the spheres 59 ft, the tubes connecting them being 9.8 ft diameter for the side tubes and 10.8 ft for the diagonals.

The spheres consist of steel framing with an insulated aluminium cladding.

(Above) Aerial view of the Atomium. On the right is a diagram showing the paths taken by the public.

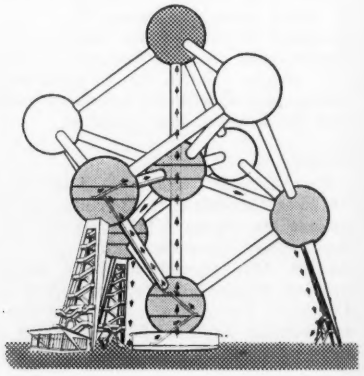
The top sphere, which has a circular concourse where 250 people can comfortably look through the windows, in addition to the restaurant, is reached in about 23 sec by a lift believed to be the fastest in Europe carrying 22 people. Access to the other spheres is by



Part of the large animated model on the NPPC stand.

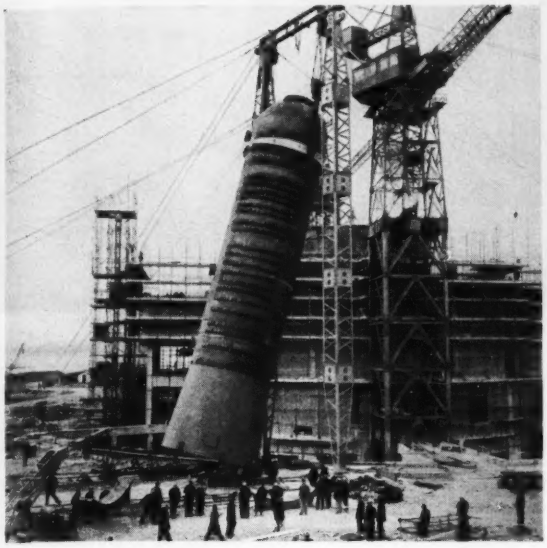
escalator, said to be amongst the longest in Europe, the largest being 114.8 ft long, with a carrying capacity of 3000/hour. The diagram shows the arrangement of escalators. Descent is by stairway located between the bipod legs of the lower sphere supports.

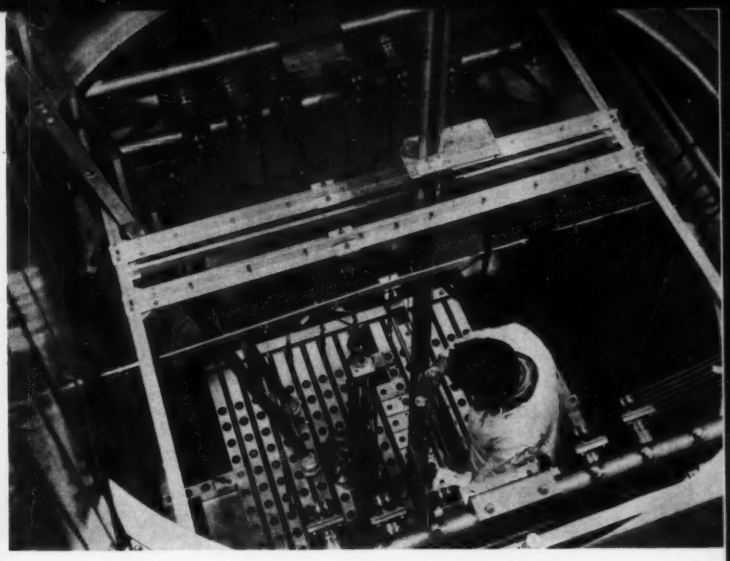
The Atomium, one of the most remarkable structures ever to have been executed, was designed and built by a consortium of the Belgian metal industry, comprising the Federation of the Metal-



working Industries "Fabrimetal," the Belgian Blast Furnace and Steelworks Group and the Union of Non-Ferrous Metals Industries. The original conception was that of M. André Waterkeyn, director of "Fabrimetal," and the consultant engineers were S.A. La Construction Soudée, the architects being MM. A. and J. Polak. Erection of the structure was carried out by the Ateliers de Construction de Jambes-Namur à Jambes.

On April 4 the first heat exchanger vessel at Berkeley was lifted into position. In the picture below, the tail bogie has been removed and the vessel is about to be lowered on to the foundations.





(Above) One of the first pictures released of NEPTUNE, the new low flux zero energy reactor at Harwell. NEPTUNE uses enriched uranium fuel elements and ordinary demineralized water at atmospheric pressure as moderator. It will be used for studying the detailed behaviour of neutrons in water-moderated core designs.

World News

International

Further discussions of OEEC's European Nuclear Energy Agency programme took place on March 24. Professor Perrin was chairman and Sir John Cockcroft vice-chairman. The meeting appointed a group of specialists to report on Britain's offer to build an experimental reactor. Recommendations on this project will be made before June 1 to Governments of the OEEC countries and to the Euratom Authority. Countries and bodies interested in the Norwegian boiling-water reactor at Halden were asked to attend a meeting in Oslo during April to make final recommendations regarding the operation of the reactor.

Board of Governors of the International Atomic Energy Agency completed its fourth series of meetings in Vienna in March. Approval was given to the general principles which will govern the Agency's fellowship and training programme. Interest was expressed in proposals to enable the Agency to grant research fellowships at the facilities which exist in a few advanced countries for using massive concentrations of beta and gamma radiation. The Agency will, on request, send a team of experts to one or more underdeveloped countries in a pilot scheme to ascertain how radiation isotopes can best be used in meeting their research and development problems. Approval was also given to a scheme to promote the exchange of scientific and technical information.

During a discussion of the Agency's activities on the supply of source and fissionable materials it was indicated that some request for materials made available to the Agency may arise as early as the latter part of the present year. The Board was informed of further offers of assistance from member states; France offered to place 20 fellowships at the Agency's disposal for the coming academic year and further details were given of the Italian Government's offer of 10 fellowships. France, India, Japan and the United Kingdom indicated that they would make available experts to be used in Agency teams to assist in formulating or evaluating atomic energy programmes in underdeveloped areas. The Governor from the United States of America confirmed that it is hoped that the U.S. Government will make available a research reactor and an isotopes laboratory at the Agency's headquarters.

IAEA's Staff Association was formally established in Vienna on March 25.

The Statutes of the Association lay down that the purpose of the Staff Association shall be to safeguard the interests of the staff and to represent it with regard to employment and working conditions. The Association will co-operate closely with the Director-general. Membership is voluntary.

About 2,500 papers are expected to be submitted at the second Atoms for Peace conference in Geneva this year. This figure compares with 1,067 at the 1955 conference. Some 600 will be orally presented this time, an increase of 33⅓%. A first list of 1,550 titles, submitted by 29 countries, was made public at United Nations Headquarters recently. Some 75 of these concern fusion experiments or studies being made in 10 countries—France, the German Federal Republic, Italy, Japan, Rumania, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. The Soviet Union has also indicated that it will send papers on the subject. The full texts of the papers are due by June 1, and supplementary information will be accepted up to July 1 or, in exceptional cases, August 1.

Graphs and tabulated data presenting the latest world figures of radioactive fallout and the absorption of the more important radioactive materials by animals and human beings were presented by Dr. W. F. Libby of the U.S.A.E.C. on March 27. He was one of the principal speakers at a symposium held in Lausanne by the Swiss Academy of Medical Sciences.

About 200 scientists from 26 nations have been invited to participate in the 1958 Annual International Conference on High Energy Physics organized by the European Organization for Nuclear Research (CERN) in Geneva, from June 30 to July 5. This meeting continues a series of seven annual conferences on high energy nuclear physics previously held at Rochester, N.Y. CERN last played host to physicists from all parts of the world at the symposium on high energy accelerators and pion physics held in Geneva in the summer of 1956.

U.S. participation in the Euratom programme was carried a stage further early in April when members of the joint working

The above panoramic view of Bradwell nuclear power station was taken during a recent Press visit by a Temple Press photographer. On the left work is proceeding on the turbine halls. Part of the 200-ton Goliath crane is shown on the extreme right of the photograph. Main contractor for Bradwell is the Nuclear Power Plant Co. Ltd.

party met in Luxembourg. Preliminary reports of the proceedings indicate that the working party will recommend initially a $200 million research programme spread over two years and paid for equally by Euratom and the U.S. Government.

United Kingdom

Dr. Gunnar Lindstrom of the Atomkraft Konsortiet, of Sweden, and directors of various Swedish electricity undertakings visited Berkeley in March. At the end of the visit Dr. Lindstrom commented that he and his party represented some 40% of the private power groups in Sweden. They had come to England to look at Britain's progress with nuclear power stations, and were deeply impressed with the amount of work that had been accomplished.

On April 3, the first of the sixteen large heat exchanger vessels for Berkeley nuclear power station was erected on site by John Thompson. The vessel, 70 ft long, 17 ft 6 in. in diameter and weighing 133 tons, was transported over a distance of some 300 yd on two bogies from the Berkeley site boiler shop, where its fabrication was completed, to its position adjoining No. 1 reactor house. Lifting into the erect position was effected by the use of a pair of gin poles, carrying tackle powered by two winches, with a 130-ft boom/15 tons Lima crane operating as a retaining winch at the rear, or base, of the vessel. Time of the lifting operation, from the point when the vessel was aligned on its centre-line and lifting tackle made fast, was approximately three hours.

Construction of the first of 12 heat exchangers for Bradwell is nearing completion at the Thornaby Works of Head Wrightson.

These heat exchangers, fabricated in $1\frac{5}{16}$ in. thick steel plate, are 95 ft long, 20 ft in diameter and weigh over 200 tons. When the first unit is completed in May it will be launched into the river Tees from Head Wrightson's slipway and towed round the coast to Bradwell at the mouth of the Blackwater Estuary in Essex. On arrival it will be landed and lifted on to its foundations by the Goliath crane recently completed.

HAZEL, a new zero-energy reactor, is now operating at Harwell. The reactor will be used to obtain basic nuclear information. HAZEL (Homogeneous Assembly — Zero Energy) uses enriched uranium fuel in the form of a salt of uranium curanyl fluoride which is dissolved in the heavy water used as a moderator. The core of the reactor is a stainless steel cylinder (7 ft high by 2 ft diameter) surrounded by a graphite reflector. The fuel solution is pumped into the cylinder from two nearby storage vessels. The system is controlled by adjusting the level of the fuel solution in the reactor vessel and by moving a vertical neutron-absorbing cadmium plate into the gap between the steel cylinder and the graphite reflector. Two cadmium plates similar to the control device are used as shut-off rods; two additional shut-off rods can be dropped vertically into the fuel solution in the reactor vessel. The reactor will be operated at a power of less than a watt and cooling is not necessary.

At Dounreay the A.E.A. is co-operating with Caithness Education Authority to provide equipment, instruments, instructors and other facilities for the new £33,000 technical college which is to be built at Thurso. This will provide training for technicians, mechanics, and other grades to be employed at Dounreay. The A.E.A. is also to provide a principal for the college.

Lucas Heights Atomic Research Establishment near Sydney, was officially opened by the Australian Prime Minister, Mr. Menzies, on April 18.

Australia

Lucas Heights Atomic Research Establishment, near Sydney, was officially opened by the Prime Minister, the Rt. Hon. R. G. Menzies, C.H., Q.C., M.P., on April 18. This completes the first stage in Australia's nuclear programme. The equipment at Lucas Heights includes the reactor HIFAR (supplied by Head Wrightson Processes), post-irradiation facilities, hot laboratories, effluent treatment plant for removing radioactivity from waste water, rolling mills and heavy presses and special laboratories for handling toxic materials such as beryllium. Australia is, of course, proceeding with a power reactor programme designed to meet her own particular requirements—a large number of small power units. It seems highly likely that the eventual system adopted will be high-temperature gas cooled with beryllium as a moderator.

Belgium

Six engineers from the nuclear division of Ateliers de Constructions Electriques de Charleroi are to spend three years studying nuclear engineering with Westinghouse Electric of U.S.A.

ACEC's nuclear division have recently received a contract for the supply of equipment for the second Belgian reactor, BR2. The company will supply reactor cooling circuits, control rods and associated mechanisms and electronic control equipment. Two other Belgian companies, Les Ateliers de Construction de la Meuse and Manufacture Belge de Lampes et de Materiel Electronique share in the contract.

France

A hydraulic pressure test has been conducted on the pressure vessel of G3 up to pressures twice that which would be experienced in normal operation. As yet, G2 has not been so tested.

New nuclear physics laboratories for the Parisian Faculty of Science at Orsay house an electromagnetic isotope separator, type E.M.2. The equipment was supplied by Gamma Industrie of Paris.

India

Annual report of the Department of Atomic Energy forecasts the establishment of one or more nuclear power stations in the immediate future. Coal for thermal power at present has to be transported distances up to 1,500 miles to the industrial areas of Bombay, Delhi and Madras and the future development of electric power independent of coal promises large economies. At Trombay about 700 technicians and scientists are employed and a further 170 science and engineering graduates are being trained.

India's first reactor APSARA, a swimming pool unit, has been in steady operation for 18 months. The much larger Canada-India reactor now under construction will be commissioned towards the end of 1959, a year behind schedule. ZERLINA, zero energy reactor for lattice investigation and new assemblies, will become critical this year.

Italy

A decree bringing into full and immediate effect the bilateral agreement with the U.K. for co-operation in the peaceful uses of atomic energy was signed by the President, Signor Gronchi, on March 29. The action was taken primarily to facilitate British bids for the SENN project.

South Africa

Exports of uranium and thorium during February were estimated at £3¼ million by the S. African Dept. of Excise and Customs. The cumulative total for the first two months of this year was £9¼ million, an increase of over 25% on the figure for 1956.

U.S.A.

EBWR — Experimental Boiling Water reactor—at the Argonne National Laboratory was successfully operated at a power level of 62 MW (thermal) in experiments on March 20. The original design level was 20 MW(T).

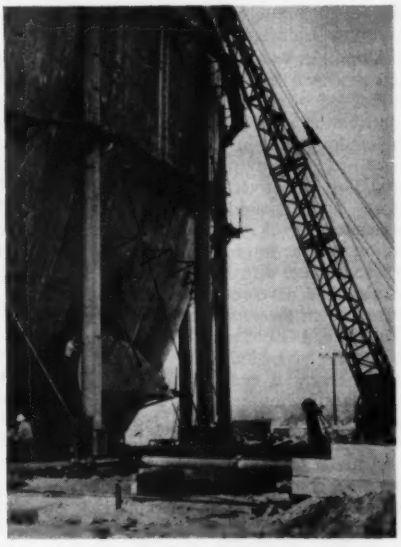
ORR—Oak Ridge Research Reactor—went critical on March 21. This high flux tank-type reactor immersed in a pool will be used for fundamental research and engineering studies on the effect of radiation on reactor materials, particularly fuel elements and structural metals. ORR will operate at a power of 20 to 30 MW(T) with an average flux greater than 1 by 10^{14} neutrons per sq cm/sec. It has a beryllium-reflected core which utilizes enriched uranium fuel elements of uranium-aluminium alloy clad with aluminium.

Skate—the third U.S. nuclear submarine —returned to her base at Connecticut on March 30 after a 34-day shake-down cruise. Her 13,000-mile tour included a record-breaking (7 days 5 hours) voyage across the Atlantic whilst submerged.

Electric power industry plans to spend some $500 million on nuclear power projects, Mr. J. W. McAfee, head of Edison Electric Institute told the American Power Conference recently. About half that sum will have been spent by the end of next year, he added.

Hazards evaluation study of the commercially owned high neutron flux test reactor to be built and operated by Westinghouse, is being undertaken by Holmes and Narver, Inc.

The 190 ft dia. steel sphere for Dresden nuclear power station, near Chicago, has now been completed. The sphere has been successfully tested at 37 p.s.i. The station is being erected for Commonwealth Edison Co.



Following the pressure test, openings were made in the sphere to enable equipment and materials to be inserted.

Orbits in Industry

THE Electrical Engineers' Exhibition was, as one expected, larger than usual, with more than 400 exhibitors, an estimated list of exhibits of 40,000 odd, and an attendance between Tuesday and Saturday of 67,000. For once, Tangent will spare his long-suffering readers (?reader) the story of how he saw it all start and, since any description is quite impossible in this page (and has already been done better elsewhere) mention just one small point which amused him. Overhearing a voice declaiming "It's too damn *big*! . . . Getting right out of hand" . . . he turned and saw a distant acquaintance regarding the enormous array of elaborate displays which now occupies practically every inch of available space in Earls Court. Memories returned of an earlier occasion when the building seemed much larger, and the stands appeared to be huddling together for protection. The same voice was speaking. "Look at it! . . . Ridiculous to have a place as big as this, for a handful of exhibits. They'll never make it pay!"

Which only goes to show that you can't please most of the people even some of the time.

Recognition

The decision—44 years after his death—to elevate George Westinghouse to the Hall of Fame at Columbia University coincides pleasingly with the successful operation of Shippingport; probably the most spectacular achievement of the Company that bears his name—although the Westinghouse brake will probably be his most enduring everyday monument.

Although Westinghouse took out his first patent at the age of 19, and was the author of some 360 in all, his major contribution in the electrical field was in the exploitation—in the best sense of the word—of the inventions of others, by providing incentive, practical encouragement, and commercial and financial assistance. Probably his greatest contribution was the introduction of a practical system of a.c. distribution. In the U.S., Stanley had developed a practical transformer from the series-connected original Gaulard and Gibbs units, Tesla developed the polyphase induction motor, and Shallenberger a practical meter, but it was Westinghouse who turned these individual efforts into a going concern, and became the father of a.c. distribution in America, which alone might almost qualify him for what is, after all, the equivalent of an Abbey memorial.

A further interesting coincidence is that Westinghouse established his first installation in Great Barrington, Mass., in March, 1886, two months after a London company had appointed a young man of 22 to do practically the same thing with their almost unworkable system. His name, of course, was Ferranti.

Brussels

As most readers will have gathered, from Press stories and the brief report that appears elsewhere in this issue, the Brussels Exhibition has a popular appeal; there is nothing for the nuclear engineer in search of new developments. It would, of course, be surprising if there were; anyone with anything new is going to save it for Geneva—if they are going to tell it at all. Mind you, one never knows beforehand whether or not something might turn up. It is very odd indeed how organizations that, for six months past, have had you practically slung off their premises for mentioning something that is held to be Top Secret, suddenly come out next day with it nestling coyly on an exhibition stand. This, of course, is caused by T.U.P. (Tangent's Uncertainty Principle) a common symptom of which is the inability to distinguish between the coronoid process and the gluteus maximus. It is, unhappily, seldom fatal.

Score for B.E.A.M.A.

One thing about Brussels that was really noticeable, however, was the resounding success of British industry in being one of the very few bits of the Exhibition that was practically finished, most of the stands at the Press preview being prepared to receive visitors when most of the other pavilions were filled with wheelbarrows and worried expressions.

Punctuality was not their only virtue, either. Both the British Electrical and Allied Manufacturers Association who, with the Federation of British Industry, were the moving spirit right from the inception of the Exhibition, and the individual manufacturers who had stands of their own, or supported B.E.A.M.A.'s effort—or both—have done a first-class job in (to use a phrase that is hackneyed yet nevertheless sincere) maintaining British prestige.

Sphere to Let?

In many ways it was a pity that Britain could not have had a show in the Atomium (or, as a friend who is also a purist—and that doesn't mean he's pure—*will* call it, Moleculum) itself. A display of the principles of nuclear energy by the U.K.A.E.A. would have taken on added glamour from being housed in that metallic fantasy. Also, it would have had more visitors, although they might not have had the time to take it all in. Tangent's own trip through the Atomium on that ill-starred Press visit left him with little time for the exercise of his faculties, beyond ensuring that he did not tread on the man in front and, even more urgently, that the man behind did not tread on him. However, to judge from other reports, general explanation in the Atomium left something to be desired, although the Westinghouse exhibit was very impressive. The U.K.A.E.A. did a remarkably good job as it was, but it would have been fun to let Cyril Darbey loose on one of the Atomium spheres. However, one can't afford everything in this world.

Buns or Gutter?

Reminiscent of the famous "Guns or Butter" choice placed before the German people in the 1930s, was a remark made in the House lately regarding careers for girls, and the choice between Science (Pure) and Science (Domestic) or, to quote verbatim, "between ZETAs and rock buns." While by no means endorsing the woman's-proper-sphere-is-the-home theory, it must be remembered that *someone* has to be able to cope with the household chores.

I married a pearl
A ZETA girl
But, when all is said and done;
I could well support
Less creative thought
And more of the old rock bun.

For omniscience
Does not make sense
When my food I have to beg;
And a Ph.D.
Is no good to me
If she can't even boil an egg.

Oh, to taste her pie
Is to venture high
In the Theory of Solid State;
But I'd be content
With some more cement
And a little less aggregate.

Well, the final squeeze
Was spaghetti cheese
Like cremated computer tape;
I said "My friend
This is The End—"
There has to be some escape.

Now it's settled that she
Returns to the
Career that she forsook;
So she's gone in
For Tech. Admin.
—AND I HAVE TO LEARN TO COOK!

Hypothesis

Among new book titles in a list that recently caught our eye was one simply entitled "The Dud Avocado." So (we mused) that ancient bugbear of our first-year chemistry lectures has blown up at last. Someone has proved that equal volumes of gases do not necessarily contain equal numbers of molecules, after all. . . . But you wouldn't have thought it would stand up to book-length treatment, would you?

Tangent

Personal

Mr. D. R. C. Guttery

Dr. L. L. Ross

Appointments

Mr. R. F. Jackson as deputy chief engineer, A.E.R.E. Harwell.

Mr. D. R. C. Guttery as chief engineer, nuclear engineering division, John Brown and Co. Ltd.

Mr. F. P. Liebert, B.Sc.(Tech.), A.M.I.Prod.E., as works manager for both the Rugby and Whetstone establishments of English Electric Co. Ltd. He will be responsible to the general manager, **Mr. E. M. Price.**

Mr. C. H. Flurscheim, B.A., M.I.E.E., Mem.A.I.E.E., chief electrical engineer, Metro-Vick, as a director of the company.

Mr. O. T. Evans, Assoc.M.C.T., A.M.I.Mech.E., A.M.I.E.E. as chief engineer, electrical general engineering dept., Metropolitan Vickers Electrical Co. Ltd. **Mr. N. R. D. Gurney,** A.C.G.I., M.I.E.E., as sales manager, plant dept., Metro-Vick. He succeeds **Mr. R. J. Cochran** who is seconded to special duties.

Messrs. H. Scrutton, M.I.C.E., M.I.Struct.E., **H. F. Merrington,** M.I.C.E., and **B. G. R. Holloway,** M.I.C.E., M.I.Struct.E., have been taken into partnership by Rendel, Palmer and Tritton, consulting engineers.

Mr. F. Limb and **Dr. J. H. Mitchell** as directors of Ericsson Telephones Ltd.

Mr. H. Pickard as a director of A.P.V. Co. Ltd.

Mr. Peter H. G. Newhouse, M.A.(Oxon), as press secretary and public relations adviser to the Scientific Instrument Manufacturers' Association of Great Britain.

Dr. Forrest F. Musgrave as personal assistant to Mr. Sydney Barratt, chairman of the Albright and Wilson group.

Mr. Everett R. Holles, formerly with the U.S.A.E.C., has joined General Atomic Division of General Dynamics Corporation as assistant to Dr. Frederic de Hoffmann, a vice-president of the corporation and general manager of General Atomic.

Mr. N. Townend as publicity manager of Quasi-Arc, Ltd. He was formerly with the publicity department of the G.E.C. Simon-Carves Atomic Energy Group.

Mr. E. G. Nisbett, B.Sc., A.R.T.C.(Met.) as metallurgist to the National Boiler and General Insurance Co. Ltd. in succession to **Mr. A. H. Goodger.**

Mr. Frank Faux, A.M.I.E.E., chief assistant engineer to the system planning engineer, Central Electricity Generating Board as station planning and development engineer.

Mr. Lars Lind (Sweden) as chief of the public information services of the International Atomic Energy Agency.

Captain J. A. Creed, V.R.D. and Bar, R.N.V.R. (Retd.) as deputy managing director of Robert Boby Ltd.

Mr. H. F. Wilson, B.Sc., A.R.I.C., A.I.R.I., F.R.S.A., Comp. I.E.E., F.P.I. and **Mr. C. L. G. Fairfield,** M.A., M.I.E.E., A.M.I.Mech.E., as directors of Telegraph Construction and Maintenance Co. Ltd.

Mr. L. W. English, technical manager, as a director of Auto-Klean Strainers Ltd.

Mr. Harry L. Hilyard, vice-president and treasurer of the American Tobacco Company as president of Industrial Reactor Laboratories, Inc.

Sir Robert A. Maclean, C.A., chairman and managing director of A. F. Stoddard and Co. Ltd. as chairman of Atkins, Robertson and Whiteford Ltd.

Dr. L. L. Ross as deputy managing director, Elliott Bros. (London) Ltd. **Rear-Admiral Sir Alexander D. McGlashan,** K.B.E., C.B., D.S.O. and **Mr. J. E. O'Breen** as directors of the company.

Mr. C. W. V. Davis, manager, filtration dept., Philips Electrical Co., Ltd., becomes commercial manager of the industrial products division on May 1. **Mr. S. G. P. de Lange,** who relinquishes his responsibilities as commercial manager, is appointed adviser to the company and co-ordinator in all matters affecting industrial products.

Mr. P. M. Holman as chairman, Climax Rock Drill and Engineering, in place of the late **Mr. R. Ewing. Mr. J. M. Williams** as a director of the company.

Mr. A. D. McKnight as a full-time executive member and **Professor Sir Leslie Martin,** C.B.E., F.R.S., as a part-time member of the Australian Atomic Energy Commission.

Retirements

Mr. W. H. Grinsted, O.B.E., F.C.G.I., M.I.E.E., director of engineering, Siemens Edison Swan Ltd., recently retired.

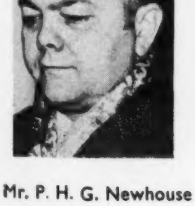
Messrs. A. J. Clark and **E. Bateson** have retired from the Rendel, Palmer and Tritton partnership but will continue to act in a consultative capacity.

Mr. Louis H. Roddis, Jnr., deputy director, division of reactor development, U.S.A.E.C., resigns on July 15 to become president of the Pennsylvania Electric Co.

Mr. W. P. Scott, condensing dept. manager, Worthington-Simpson, Ltd., retired on March 31; the dept. is now administered from Newark by **Mr. T. Trowsdale,** condensing sales manager, and **Mr. T. Bennett,** condensing contacts manager.

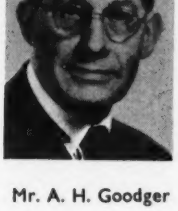
Mr. A. H. Goodger, M.Sc. (Tech.), A.R.I.C., who has been head of the metallurgical department of the National Boiler and General Insurance Co., Ltd., for many years, retired from full-time service on April 12. Among his future activities, Mr. Goodger is being retained in the capacity of consultant metallurgist by Kennedy and Donkin, the consulting engineers.

Mr. Leslie C. Brown, Birmingham office manager and technical representative of G. and J. Weir, Ltd., retired on March 31. He is succeeded by **Mr. Gavin Murison,** who has been transferred from Weir's London office.



Mr. P. H. G. Newhouse

Mr. H. L. Hilyard



Mr. A. H. Goodger

Ambassador Pavel Winkler, chairman of the board of governors, International Atomic Energy Agency, **director-general Sterling Cole** and one of the deputy directors-general, **Dr. Paul R. Jolles,** made a study tour of the Soviet Union during April. The IAEA team visited national and international nuclear installations and research institutes in Moscow, Dubna and Leningrad.

Obituary

Nuclear Engineering records with regret the death of the following personality:

Sir James Swinburne, Bt., M.I.E.E., F.R.S., died on March 30, one month after celebrating his 100th birthday. The father of the British plastics industry, he was until 1948 chairman of Bakelite Ltd.

Dr. P. C. Thonemann (left) and Sir John Cockcroft receive the silver medal of the Hulton Award from Sir Edward Hulton.

(Below) The trophy presented to the ZETA team was created by Tacita Fontana.

ZETA Team Presentation

One year ago Sir Edward Hulton announced that he would present an Achievement Award annually to the individual or group who contributed most to the prestige of Great Britain. It was particularly fitting, therefore, that the presentation of the first award should be made to the team responsible for the creation of ZETA. The presentation—comprising a silver trophy, a cheque for £1,000 and an inscribed silver medal—was made by Sir Edward at the Savoy, London, on April 15.

The ZETA team, headed by Sir John Cockcroft and Dr. B. F. J. Schonland, comprised: Dr. P. C. Thonemann, Dr. R. Bickerton, Mr. E. P. Butt, Mr. R. Carruthers, Dr. A. Dellis, Mr. D. W. Fry, Dr. A. Gibson, Mr. G. Harding, Mr. D. J. Lees, Mr. R. W. P. McWhirter, Mr. J. T. D. Mitchell, Mr. R. S. Pease, Dr. S. A. Ramsden, Mr. R. Tayler, Dr. W. Thompson and Mr. S. Ward. The panel of judges responsible for the award included Lord Brabazon of Tara, Mr. C. S. Garland, Dr. R. W. Holland, Col. Sir Charles Ponsonby, Sir William Rootes and Sir Miles Thomas.

The BEAMA Catalogue

Nuclear power plant is mentioned for the first time in the current issue of the BEAMA Catalogue, the fourth edition of which has just been published. The descriptive catalogue pages have been designed throughout to a standard format, each division being printed in a distinctive second colour. Over 690 pages of profusely illustrated announcements display the products manufactured by member-firms. The divisions are classified as: (a) electrical power plant (blue); (b) electrical equipment in industry, transport and communications (maroon); and (c) domestic and commercial electrical appliances, lighting, accessories and installation material (orange).

A five-language glossary of technical terms used in the buyers' guide is included to help overseas buyers not fully conversant with English terminology. Product headings are listed in English, French, German, Portuguese and Spanish, thus providing a comprehensive cross-reference in five languages—a useful key to the technical equivalent terms used in other countries.

The classified buyers' guide lists under more than 1,300 headings the comprehensive range of electrical and allied equipment manufactured by BEAMA firms. The trade directory gives the principal addresses of all BEAMA member-companies in the U.K., subsidiary or branch offices, and over 4,780 names and addresses, grouped territorially, of members' overseas branches, representatives and agents. A list of addresses of the BEAMA overseas committees is also given. The BEAMA Catalogue is published for the British Electrical and Allied Manufacturers' Association, Inc., 36 Kingsway, London, W.C.2, by Iliffe and Sons, Ltd. 962 pages. 12 in. by 8¼ in. Price £6.

Trade Literature

Technical data sheet No. 5B, giving the physical characteristics, chemical properties and analysis of crystalline boron, has been published by Borax Consolidated, Ltd. The company announced in July last year that they were marketing crystalline elemental boron in the pure state, and the two types dealt with in the technical data sheet show that the purity is as high as 99.15% and 99.6%. The low oxygen and nitrogen content makes the product particularly suitable for incorporation into alloys, and it is expected to be of interest to the electronic and metallurgical industries, and also for certain nuclear applications.

(Borax Consolidated, Ltd., Borax House, Carlisle Place, London, S.W.1.)

The E.B. Weld Insert process, introduced to this country recently by Rockweld, is described in a new leaflet. The E.B. Weld Insert is used for pipe joints where a root run weld must be of the highest quality. It comprises a wire of special section, which is fitted between the prepared ends of the pipes to be joined, and subsequently fused to provide a top-quality weld, and a smooth contour both internally and externally. The insert has been used in the United States in the construction of nuclear-powered submarine "Seawolf."

(Rockweld, Ltd., Commerce Way, Croydon, Surrey.)

Facilities and accomplishments of the Atomic Power Department of United Shoe Machinery Corporation are described in a new two-colour brochure. The Atomic Power Department, established in 1955, provides a completely integrated service for research, design, engineering and manufacturing of mechanical systems and components for the atomic energy industry. The booklet describes this organization's contributions to various nuclear programmes, including nuclear submarine reactors and the nation's first large-scale surface nuclear power plant. A test facility for environmental testing of mechanical components and systems for pressurized water reactors and fuel handling equipment is maintained by the Atomic Power Department for assignment to a wide range of nuclear programmes.

(Atomic Power Department, Research Division, United Shoe Machinery Corporation, Balch Street, Beverly, Mass.)

A twenty-four-page catalogue, ref. MCW.101, issued by Mersey Cables Works, gives full details of the many different categories of wiring cables now available from the company for use in the electrical industry. The catalogue is sub-divided into three types of cable insulation: vulcanized rubber, PVC and polythene. Each type of wiring cable included under these headings is illustrated, and details of dimensions, approximate weights per 1,000 yards, and full specifications, are given. Aspects of the company's research and development work on insulating materials and cables are also described and illustrated.

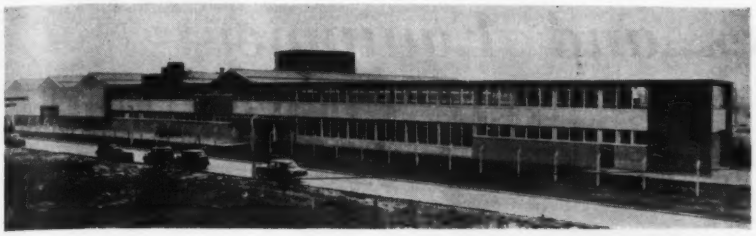
(Mersey Cable Works, Ltd., Linacre Lane, Bootle, Liverpool, 20.)

A new 180-page welding data book, describing simplified welding procedures for application to all metals at reduced temperatures, is now available from Eutectic Welding Alloys. The pocket-sized data book is a guide to improved welding techniques with torch and electric arc, and contains useful information on maintenance, repair, salvage and fabrication with all metals. Procedures are described for obtaining maximum machinability in work-time and costs, with superior weld quality. A large number of applications for welding in every industry is given, including joints requiring special properties such as high electrical conductivity, resistance to corrosion, and suitability for tinning and coating. Welding procedures which save dismantling and eliminate pre- and post-heating are also mentioned. A full, practical discussion of Eutectic's low heat input metal-joining process points out its greater flexibility, easier application and other advantages over welding with conventional materials.

(Eutectic Welding Alloys Co., Ltd., North Feltham Trading Estate, Faggs Road, Feltham, Middx.)

Remote handling equipment, electronic control gear, testing apparatus and special purpose machinery made by the Ayling Industries Group of companies are described in a new brochure available from the Group's sales organization, the Ayling Nuclear Equipment Company. Apart from the English text, the brochure contains translations in French, German and Spanish and illustrates a number of the Group's products which also include magnets, cyclotron components, pressure and vacuum vessels, and control panels.

(Ayling Nuclear Equipment Company, Horsham, Sussex.)



(Left) Western Manufacturing's new factory at Southampton.

Industrial Notes

Following the official opening of the Instruments, Electronics and Automation Exhibition by Sir David Eccles, president, Board of Trade, on April 16, the organizers held a luncheon at Olympia. This year the scope of the show has been widened to include equipment of foreign manufacture and the guests included a large number from overseas. They were welcomed by the chairman of the organizing committee, Mr. E. W. Semmens. Sir Henry Self, chairman of the Electricity Council, in replying for the guests spoke warmly of the remarkable expansion of the British instruments industry in the past few years.

Kontak Manufacturing Co., Ltd., of Grantham, have been acquired by E. V. Industrials, Ltd. At the A.G.M. of the parent company, Mr. Michael Lewis, chairman and joint managing director, said that in response to an advertisement in *Nuclear Engineering* inquiries for the Kontak metering unit had been received from a number of countries including Japan, Sweden, France and Italy.

Atomic Power Constructions, Ltd., and **Babcock and Wilcox, Ltd.,** announce that in August, 1957, an agreement was completed whereby Babcock and Wilcox will undertake detailed design, manufacture and erection of the reactor pressure vessels forming part of nuclear power stations supplied by A.P.C. or member companies. Babcocks will also supply any heavy-cranes required for site erection.

Oil Feed Engineering Co., Ltd., of 18 Denbigh Street, Victoria, London, S.W.1, manufacturers of high-pressure flexible hose assemblies under the Hi-Flex trade mark, have now become a member of the BTR group of companies and will operate as the high-pressure hose division of the group.

Abstracts for papers to be presented at the Seventh Conference on Hot Laboratories and Equipment to be held in Cleveland, Ohio, in April, 1959, are due before September 15, 1958, and should be sent to the programme chairman: L. G. Stang, Jnr., Brookhaven National Laboratory, Upton, New York. Papers are invited on all phases of hot laboratories and equipment for handling radioactive material including design, construction, operation, maintenance, decontamination, remodelling, shielding calculations, costs, etc.

Western Manufacturing (Reading) Ltd. have opened a new factory on the Millbrook trading estate at Southampton. The factory is engaged on an A.E.A. contract, supplying both engineering and electronic manufacturing facilities.

NETAC—Nuclear Energy Trade Associations' Conference—of 32 Victoria Street, London, W.1, announces that it has reserved more than 40,000 sq. ft of floor space at the Palais des Expositions for the second Atoms for Peace exhibition. The reservation, on behalf of British industry, is believed to be larger than that made for any other country.

British companies who wish to place posters in Geneva for the period of the conference (September 1 to 14, 1958) might like to know that all poster space can be booked only through Société d'Affichage, Geneva.

20th Century Electronics Ltd. of New Addington, Surrey, have recently signed a long-term agreement with the U.S. firm Edgerton, Germeshausen and Grier of Boston. This agreement includes provision for the manufacture, under licence, of the E.G. and G. travelling wave cathode ray tube with interchange of technical advice and know-how. 20th Century are granted exclusive sales rights in the United Kingdom for the E.G. and G. tube which is considered the most advanced high-speed recording tube of its kind in the world.

Winston Electronics have received another order for over £70,000 from Italy for electronic equipment, which includes spectrum analysers and highly stabilized decade oscillators.

SENN—Società Elettronucleare Nazionale has moved from Via Savoia 15, to Via Torino 6, Rome.

Eversbed and Vignoles Ltd., have opened a branch office at Succursale, 142 Rue Gallait, Brussels. Mr. C. Samyn is in charge.

Warren, Morrison Ltd., manufacturers of diaphragm valves, have moved to 41 St. James's Place, London, S.W.1. Telephone: Mayfair 9895.

Wolf Electric Tools Ltd., have acquired an additional factory—on the Slough Trading Estate—for promoting planned technical developments.

Electroflo Meters Co. Ltd., are now using their Minerva Works at Park Royal, N.W.10, solely for the construction of instrument panels, instrument cases and appropriate welding facilities. Recently Electroflo (themselves members of Elliott-Automation) acquired the whole of the share capital of **Gilmoor Control Systems.** The company has moved from Watford to the main Electroflo building.

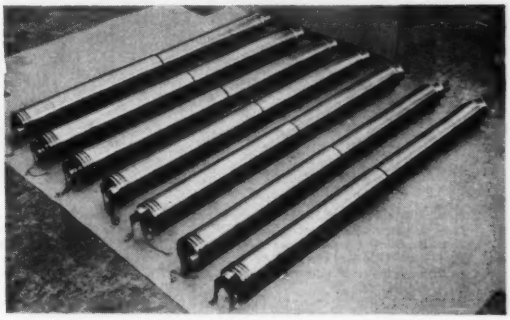
General Descaling Co. Ltd., have just opened a new sales office at 79-80 Petty France, Westminster, London, S.W.1. Telephone 5538. Recent contracts of the company include one for descaling heat exchanger tubes at Calder Hall. Mr. S. A. Rickwood is in charge of the London office.

Savage and Parsons Ltd. of Watford recently completed a £21,000 export order for 160 fuel element shield plugs for HIFAR —High Flux Australian Reactor—at Lucas Heights, near Sydney. They are similar in design to those produced for DIDO and PLUTO at Harwell, and for DMTR at Dounreay.

A further export order for 130 similar plugs has also been received from Denmark, and delivery, at a rate of 40 a month, will begin next July. When this order is completed, Savage and Parsons Ltd. will have produced nearly 700 plugs worth approximately £85,000.

Each fuel element plug is 4 ft 6 in. long and 4¼ in. diameter. The body is a titanium-stabilized stainless steel tube filled with concrete and iron shot, to a density of 350 lb. per cu ft, and a 4 in. layer of lead.

Also housed in the main tube there are three stainless steel purge tubes, through which air or gases can be cleared from around the fuel element, and a centre plug which can be withdrawn to facilitate the removal of water and chemicals from the core of the reactor. The fuel element and cooling sheath is attached to the bottom of the plug by a clamping ring.



Seven of the fuel element plugs for the Lucas Heights experimental reactor in Australia photographed at the Watford factory of Savage and Parsons Ltd.

Processes and Equipment

Inexpensive Geiger Counter

A new low-cost, general purpose geiger counter—capable of detecting gamma, hard beta and x-radiation—has been introduced by Radiation Monitors. Manufactured under licence from the A.E.A., the unit makes use of a patented circuit evolved at A.W.R.E.

Self-contained, light weight and portable, the instrument employs the latest type of highly sensitive low-voltage halogen-quenched tube. There are three ranges of visual response indicated by flashing neon together with a loudspeaker count of each single ionizing event at low radiation levels. As a guide to sensitivity, typical background counts over chalk areas are 40-50 counts per minute, while over West of England granite, away from metalliferous areas, counts range from 110-180 per minute, according to locality.

High-tension power is derived from a battery pack of internationally available 30-volt batteries. These are assembled in the plastic case which is moulded from high-impact polystyrene for maximum durability and good insulation resistance. The current consumption under normal conditions is so low (a millionth or so of an amp) that with proper use the batteries have a very long life.

Thumb-operated controls permit single-handed operation on the medium and low ranges, but an extra long shoulder strap is provided for convenience when field surveying or prospecting for thorium or uranium ores. A pulse output socket enables a miniature crystal earpiece, oscilloscope or recording scaler, to be substituted for the internal speaker. The overall size of the unit is 9 in. by 6 in. by 3 in.; weight 3 lb. Simplicity of design and construction have permitted the marketing of this useful tool at £10 plus £2 15s. 3d. for batteries. A miniature crystal earpiece is available as an optional extra.

(Radiation Monitors, Ltd., 52 Tottenham Court Road, London, W.1.)

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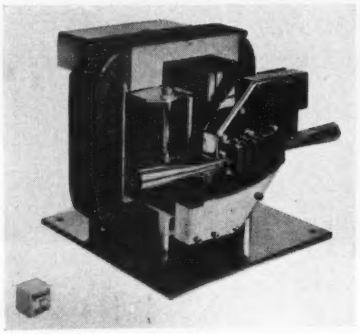

Electromagnetic pump of 6 g.p.m. capacity for circulating conducting liquids in the laboratory. (British Thomson-Houston Co., Ltd., Rugby.)

1108

General purpose geiger counter by Radiation Monitors, Ltd.

Remote Measurement

Measurement of dimensional changes of specimens which have been subjected to irradiation presents quite a problem to personnel engaged in remote handling. Recently Thomas Mercer, Ltd., in conjunction with U.K.A.E.A., produced a dial gauge for this purpose.

The device is capable of handling specimens of varying dimensions. They can be held, rotated, turned over and inspected for outside dimensions, thickness and parallelism—and any dimensional change can be quickly measured. The unit is manually controlled by an operator outside the hot cell. Particular attention was given to the design of the gauging devices so that they would not require adjustment or maintenance after installation.

(Thomas Mercer, Ltd., Eywood Road, St. Albans, Herts.)

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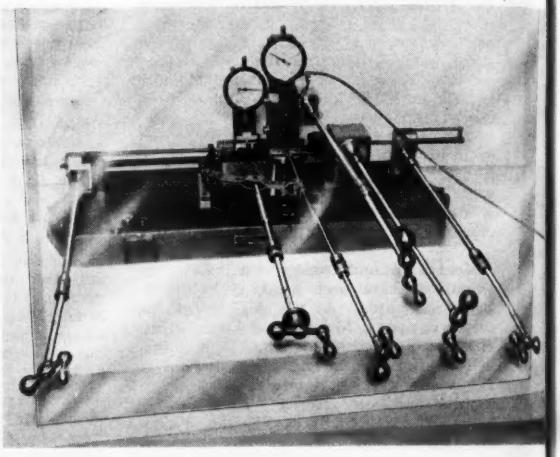
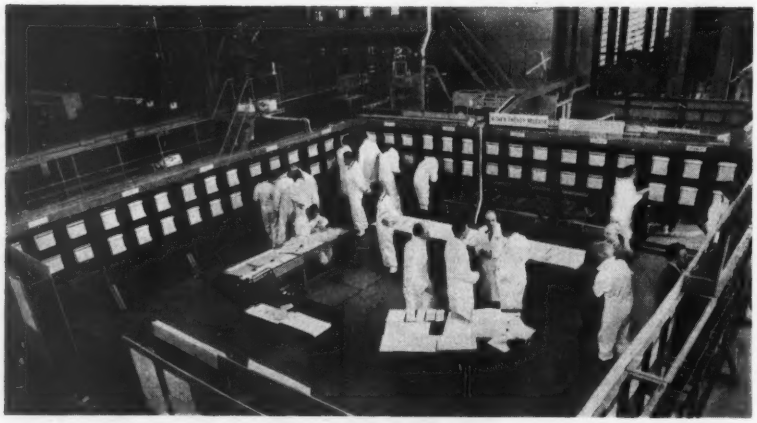


Special rig devised by Thomas Mercer, Ltd., for measuring dimensional changes of irradiated specimens.



Kent Multelec recorders were among the instruments used to register temperatures during the Wigner energy release of BEPO on March 15-16. By pre-heating the air entering the reactor during a ten-hour period, the temperature of the graphite structure rose to about 90°C; at this point, a slow release of stored energy began, although the main release occurred when the temperature reached 120°C. The temperature of the graphite rose to a maximum of 330°C.

1109

Novel Solenoid Valve

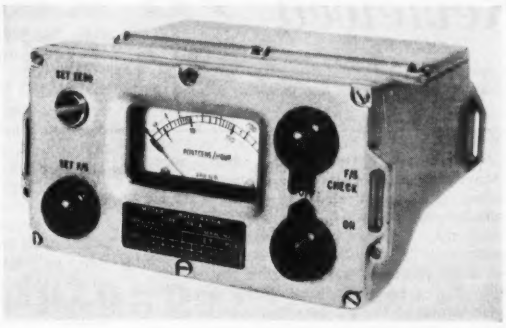
It is often necessary for a solenoid operated fluid power control valve to be actuated when the electrical supply is not available. This is required when there is a supply failure or during installation and testing of the equipment. To meet this demand, Baldwin Instrument Co., Ltd., have introduced a novel mechanism which permits a valve to be manually operated.

Operation is by means of a shaft which enters through the end cover of the valve and makes contact with the pilot piston head which in turn is connected to the spool. When the over-ride shaft is depressed, it moves the spool from the "normal" to the "operated" position. The spool can be locked into the operated position by rotating the over-ride shaft when it is fully depressed, whereupon a "D"-shaped collar on the shaft locates behind the head of a locking screw. The locking position is positively indexed which ensures that the mechanism remains firm in the event of vibration.

(Baldwin Instrument Co., Ltd., Brooklands Works, Dartford, Kent.)

1111

Philips transistorized radiation monitor.



Radioactive survey meter by Plessey Nucleonics.

Transistorized Radiation Monitor

A new transistorized pocket radiation monitor (Type PW 4014), which utilizes printed wiring has been introduced by Philips Electrical, Ltd. The instrument—watertight and fully tropicalized—is designed for general survey, location and measurement of radioactivity. It weighs only 1 lb 5 oz and by virtue of the small dimensions—6¼ in. by 4 in. by 1¾ in.—it can be carried easily in the pocket. A built-in G-M tube enables the instrument to be used as a probe for measuring gamma radiation and a separate mica end-window G-M tube with a flexible lead can be plugged into the instrument for beta measurements.

Two measuring ranges are incorporated: one for high and the other for low sensitivity. An accurately-balanced, easily-readable meter calibrated in mr/h (radium gamma radiation) indicates the radiation intensity. A small earphone can be connected for the audible detection of very low intensities. The power supply is a 3 V flashlight battery or two miniature 1.5 V cells. The all-transitorized circuit has a low drain, so that long battery life is assured. The basic unit sells at £47 10s. Accessories include a G-M probe for beta measurement (£11), and earphone (£3).

(Philips Electrical Ltd., Century House, Shaftesbury Avenue, London, W.C.2.)

1112

Survey Meter

Plessey have also developed a low-cost radioactivity survey meter (Type 1541A)—primarily for measuring high intensity gamma dose rates in contaminated areas. This battery-operated survey meter measures gamma radiation over the range 0 to 500 r/h. Weighing only 4½ lb (2 kg) complete with batteries, it can be supplied with a carrying strap and a body strap to give the user complete freedom of movement.

The dose rate is indicated on a direct reading meter which has an approximately logarithmic scale; overall accuracy is ±20%, and the energy response is constant to within ±10% from 100 keV upwards. The scale is visible over a wide angle which facilitates its use under operational conditions with reasonable accuracy. Overall dimensions of the meter, which is contained in a die-cast aluminium case, completely sealed, are 5½ in. by 3 in. by 5¾ in. An alternative model for beta/gamma measurement has also been developed; in this unit, measurement of combined beta and gamma radiation dose rate, or gamma radiation only, is selected merely by opening or closing the beta window flap. The basic meter (Type 1541A) costs less than £15.

(Plessey Nucleonics Ltd., Weedon Road, Northampton.)

1114

Offshore Drilling Tower

To ensure a solid foundation for the cooling-water intakes of the Hinkley Point nuclear power station, an offshore drilling tower was erected so that rock samples could be taken from 50 ft below the sea bed. The tower used for this work was constructed from 2-in.-diameter steel scaffold-tubing and spring-steel fittings, supplied by the Bristol Branch of Mills Scaffold Co. The framework, stiffened with cross tubes, was erected on site, slung between two pontoons, towed to the drilling position 2,000 ft offshore and then sunk in a mean depth of 40 ft of water, the tower at high tide standing 30 ft above sea level. The structure was stabilized by attaching it with guy ropes to concrete blocks resting on the sea bed.

(Mills Scaffold Co., Ltd., Trussley Road, London, W.6.)

1115

Welding Pressure Vessels

At the Wolverhampton factory of John Thompson, a Unionmelt installation supplied by Quasi-Arc is now being used for the welding of large cylindrical pressure vessels. A Unionmelt U.E. welding head is mounted on a high-lift boom which is 17 ft 6 in. in length. A catwalk with hand safety rails enables the operator to move freely between the welding station and a platform at the fixed end of the boom. This platform carries a hopper for welding powder, together with a powder recovery unit which returns unused powder to the hopper.

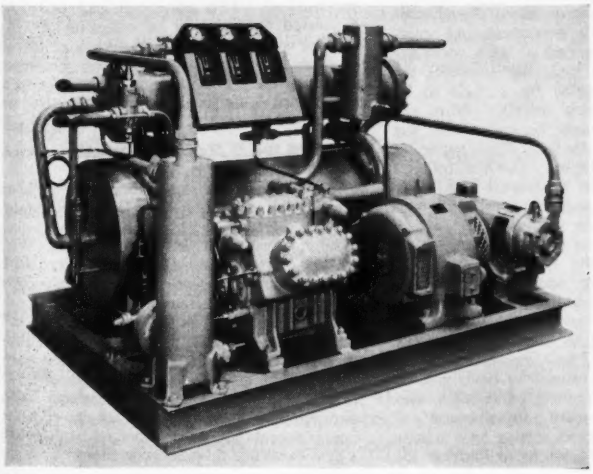
The boom is raised and lowered by a vertical lead screw driven by an electric motor. All main electrical controls, including those for raise-lower of the boom and traverse and rotation of the roller bed, are built into the bulkhead panel. They are situated conveniently near the operator who is carried by the machine in a suitably-designed lay trough Raise-lower of the boom permits external longitudinal and circumferential welding of vessels from 2 ft 6 in. to 18 ft in diameter. It also permits internal welding of vessels with diameters of 6 ft 6 in. and upwards.

(Quasi-Arc, Ltd., Bilston, Staffs.)

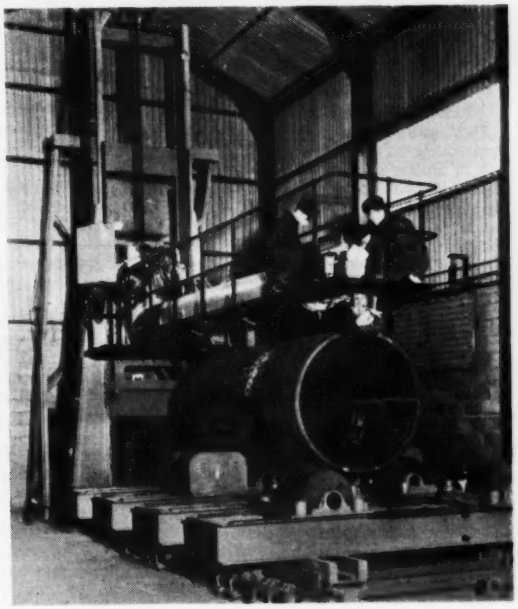
1116

(Below) A new range of packaged water chilling equipment has just been introduced by Lightfoot Refrigeration. The units are available in graduated capacities from 10 to 100 b.h.p. and the smallest unit (shown here) measures 6 ft by 4 ft by 3 ft 9 in. high.

1113



(Right) Unionmelt installation for welding cylindrical pressure vessels of up to 18 ft dia., 30 ft long and 48 tons in weight.



Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 785,528. Nuclear reactor plant. To: Allmanna Svenska Aktiebolaget (Sweden).

In order to reduce the otherwise required great thickness of a pressure vessel enclosing reactors for large power, and, therefore, of large dimensions (thicknesses of 20 cm have been mentioned in the literature), the reactor is inserted into a space formed in rock so that the rock, preferably provided with a thin smoothing layer of concrete, takes up the pressure stresses to which the walls, bottom and top of the reactor vessel are subjected. Water may also be used as pressure transmitting medium between reactor vessel and rock wall. The vessel can then be constructed with comparatively small thickness. Used fuel elements are removed and new elements inserted through a vertical mounting shaft. Expansion stresses are avoided by keeping the vessel at low and constant temperature by cooling. The vessel may also be provided with an inner thin corrugated wall filling the space between both walls with cooling water under the same pressure as the pressure vessel. Or resilient joints may be arranged between suitable parts. Sliding movement between rock wall (concrete) and vessel may then be facilitated by interposition of a thin cover sheet. Or the vessel may be positioned freely in the rock space, the interstice then being filled with a medium of the same pressure as the internal pressure in the vessel.

B.P. 785,602. Extraction of uranium from its ores. T. V. Arden, F. H. Burstal, R. P. Linstead. To: U.K. Atomic Energy Authority.

Uranium having a very low phosphate content is extracted from phosphatic ores by treatment with concentrated sulphuric acid. A system is formed comprising a liquid sulphuric acid-phosphoric acid phase and a solid phase containing all or the greater part of uranium content of the ore and the solid phase is then separated out by centrifugal means. The solid phase obtained is taken up with water and treated with a soluble barium salt and filtered.

B.P. 785,611. Chemical reactions. To: Esso Research and Engg. Co. (U.S.A.).

The steady accumulation of radioactive by-products or waste materials in the operation of atomic piles presents a disposal problem. The difficulty can be alleviated by using the material for certain reactions. The radioactive material is maintained in the lower portion of a ground excavation under a shielding material. The reactant material is introduced or kept in the lower part of the excavation sufficiently close to the radioactive material to allow the radiation to reach the reactants. It is preferred to expose the reactants to radiation emitted by the fission by-products of processes generating atomic power and/or fissionable materials. The activation of chemical reactions by high energy ionizing radiation is somewhat complicated by the fact that most reactions are between elements of low atomic number (21 or lower), which do not effectively absorb, e.g., gamma-rays. Such mixtures can be sensitized by incorporating elements of high atomic number (22 or greater; preferably 74), such as mercury in the form of a solution, suspension or emulsion or as mercury vapour in a hydrocarbon mixture. Ultrasonic vibration may be introduced to obtain more uniform or more stable emulsions or suspensions. Instead of elements of high atomic number, compounds may be used. The additions may range between 1 and 5% of the reactants. The method may also be applied to chain reactions which involve the production of free radicals. Water may be maintained in the pit as a transparent shield over a thin layer of concrete covering the concrete or metal-lined pit.

B.P. 785,641. Process for the preparation of fluorocarbons. To: U.K. Atomic Energy Authority (U.S.A.).

A method of catalytic fluorination of hydrocarbons by which high yields exceeding 50% fluorinated product can be obtained. Fluorine and the organic compound in the vapour phase are mixed in the presence of a catalyst (described in U.S.P.2,510,864 comprising a heat conductive metal base having thereon an adherent layer of a fluorine of silver, cobalt, manganese or cerium) at a temperature of 100 to 400°C.

B.P. 785,862. Heat exchange systems. A. Bell. To: Foster Wheeler, Ltd.

A shell and tube heat exchanger for the heat exchange between a first fluid (molten sodium or radioactive water) and a second fluid (steam or non-active water) where it is important that the two fluids should not come into contact. The most likely point for leaks to occur is at the joints between the tubes and the tube plates. Double tube plates are used, and the space between them is supplied with a gas or vapour inert to either fluid under a pressure equal to that of the liquid. An expansion tank may be arranged in accordance with B.P. 772,765, and a leak detector may be connected to the space between the tube plates.

B.P. 785,886. Nuclear reactors. H. H. L. Ritz. To: C. A. Parsons and Co., Ltd.

A high heat release from the surfaces of fissionable material or its containers in the core is difficult to achieve by circulation of fluid or coolant through the core. The problem of removing the heat generated in the reactor is easier to solve when the heat is transferred to a heat receiver or a medium outside the core. The method here suggested consists in using one or more closed containers filled with a non-circulating intermediary fluid. One end of each container is heated by the heat generator (reactor), the other end being cooled by a fluid to be heated (water or liquid metal). When the temperature in the core begins to rise, the non-circulating intermediary fluid vaporizes and the pressure increases. The heat transfer at the fuel end into the liquid filled part of each container remains good, the heat transmission from the vapour filled part to the surrounding liquid to be heated is poor. By initially filling the containers with the intermediary fluid to such an extent that pressure and temperature tend to assume simultaneously their critical values, the heat transmission can be so controlled that any further temperature and pressure rise is counteracted. The process of heat removal is then stable. A control mechanism may be provided responsive to pressure or temperature in order to reduce heat release in the core of the reactor or to increase the heat removal by the fluid to be heated as soon as the values exceed the critical values.

B.P. 785,928. Nuclear reactors including horizontal graphite bars. To: Commissariat à l'Energie Atomique. (France.)

Resilient means (springs) are interposed between the surrounding structure and the graphite blocks so as to fix them firmly in the desired position, but permit expansion. The resilient means must be strong enough to overcome the friction between the blocks of each row and those of the adjoining rows. Vertical gaps between the rows are maintained by struts of low neutron absorption, i.e., beryllium or zirconium. These struts are located at points common to three graphite bars in order to reduce their number to a minimum.

B.P. 785,945. Pressure vessels. R. N. Millar, K. J. Mitchell. To: General Electric Co., Ltd.

In order to improve the rate of heat transfer in a thermal reactor, gas at relatively high pressure is employed (100-200 lb/sq. in.) and the problem arises to build a suitable pressure vessel which can be assembled on site using conventional and well-known constructional methods. The new vessel (spherical, cylindrical or of any other suitable shape) is built up of an outer shell and an inner shell which is heat resistant and acts as a lining spaced from the outer shell. The cooling gas first flows in the space between the lining and the outer shell and then into the reactor core to cool the fuel elements. It is also possible to arrange separate circuits for two cooling media. The outer shell may be of low-quality steel and of welded construction while the inner shell, the lining, is of heat-resisting steel and riveted or bolted.

B.P. 785,997. Method of the recovery of uranium products from solutions containing hexavalent uranium. To: A.B. Atomenergi (Sweden).

The conventional method of precipitating uranium from aqueous solutions containing hexavalent uranium by the addition of ammonium hydroxide, alkali metal hydroxides or alkaline earth metal hydroxides results in a product difficult to separate from the solution. The process is very laborious and complicated. A method much easier to carry out, easy to control, and cheap, consists in dissolving in an aqueous solution containing hexavalent uranium one or more amides to form a homogeneous solution, and heating the solution to cause the amide to hydrolyse whereby the pH value of the solution increases and ammonium uranate is precipitated. This precipitate can easily be separated by filtration or centrifuging. As a rule, carbamide is the preferred amide as it provides a quicker and more complete precipitation. The product easily falls to a powder of a uniform grain size so that no grinding or screening is necessary.

B.P. 786,194. Radiation detecting device. P. W. Martin, R. W. Pringle.

The exploration unit operates with a scintillation crystal, a large mass of sodium iodide activated with thallium, converting gamma rays into light scintillations. The crystal must be kept cool and dry to work properly. As the detector is to be used for the remote exploration of underground oil-bearing formations a multi-compartment cell structure is used with outer walls of low thermal conductivity. One of the compartments contains the means responsive to radiation bombardment, e.g. gamma rays, another one is a cooling medium and the compartments are interconnected to establish a heat exchange flow between them.

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Shippingport—An Appraisal

SHIPPINGPORT power station was due to be dedicated at the end of May, more than five months after its first operation at full power. Although the reasons for the delay are unknown, they certainly do not reflect upon the value, nor the importance of the project, despite the high generating costs (64 mills/kWh) that are quoted in the official report.

Shippingport is claimed to be the world's first nuclear power station designed solely for civilian use, although certain aspects of the design are reminiscent of naval tradition. The whole plant, however, is essentially a prototype or experiment rather than a direct attempt at competitive power, and there is a danger in emphasizing the civilian aspect that the engineering and the cost will be taken as typical of the PWR system rather than typical of a " one-off " job in very special circumstances.

Operationally, the station has so far fulfilled the highest expectations. The run-up to full power from critical was made in a remarkably short space of time (about three weeks) and the reactor portion gave practically no trouble at all. As is inevitable, certain commissioning problems were experienced but these were confined to the conventional sections of the plant. Fuel handling techniques were also not perfect and some modifications were necessary to the element handling tongs but this could hardly be classed as an operational difficulty. To date the reactor has proved stable at all power levels, responding to load changes in the same manner as the Nautilus power unit. Fuel element performance has also been according to design with no failures. At present, the plant is undergoing an extensive series of tests to prove its overall capabilities.

Flexibility

It is perhaps unfortunate that a little more flexibility was not built-in to the reactor so that these tests could be more exacting than is at present possible, particularly in view of the rather dramatic results that are being obtained on the boiling water reactors. It is possible that future designs of large light water-cooled reactors will call for a compromise between the BWR and the PWR systems (this subject will be covered at greater length in a subsequent issue of *Nuclear Engineering*), but it is difficult to see how Shippingport can be used to provide data on partially boiling cores. Nevertheless the plant will add appreciably to the considerable store of information already collected on the PWR and—of equal importance—will develop confidence in the practicability of the system.

Economics

Regarding economics, it must be remembered that a policy of certainty-above-all was adopted (as with Calder Hall) and the generation cost probably bears less resemblance to that possible in a commercial plant than the (undisclosed) cost of power from Calder bears to that from stations now under construction in the United Kingdom.

In its analysis, the A.E.C. has made certain that it cannot be accused of over-optimism. The primary cost, in round figures, was $72m, including the first seed and blanket which is then made equivalent to a capital investment of $68m excluding the core but including $8½m for design engineering. In addition, the power output is quoted at 60 MW whereas the second core at least will generate 100 MW and this is probably not a limiting figure. The generator set alone is quoted at $175/kW (installed capacity) which is high even allowing for poor steam conditions.

Construction by committee, especially a " first-off," must inevitably result in increased costs. Moreover, the rigid time-table must have resulted in the special manufacture of many parts that could have otherwise been practically standard items. To compensate in some degree for this, of course, many components were probably supplied at specially low prices by manufacturers anxious to gain experience in the nuclear field.

The dominant factor, though, was the " better than best " policy which is inescapable in the case of an experimental station. A particularly inconvenient (and therefore expensive) requirement was that of the containment which was spread out over four separate (though interconnected) underground vessels which had to be fabricated and tested before the installation of the reactor and its associated plant. A more compact design, and a more logical construction schedule, would make a significant difference to the capital cost, as would the cumulative effect of many of the special requirements of the smaller components. The main coolant pipes, for example, require a smooth finish inside to resist corrosion and erosion while a smooth finish outside would assist in testing, but the machining of both surfaces to